Energy, Mines and Resources Canada
Hon. Marcel Masse
Minister

Énergie, Mines et Ressources Canada
L'Hon. Marcel Masse
Ministre

CANMET

PHYSICAL METALLURGY RESEARCH LABORATORIES

ANNUAL REPORT FY 1985 - 86

PMRL 86 - 40 TR

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PHYSICAL METALLURGY RESEARCH LABORATORIES

ANNUAL REPORT FY 1985 – 86

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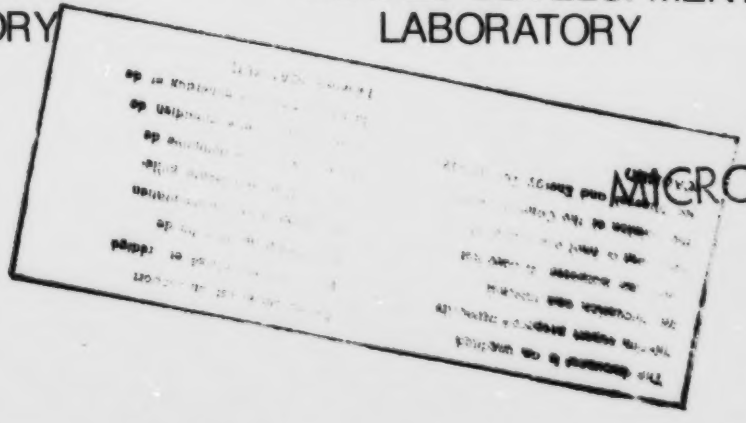


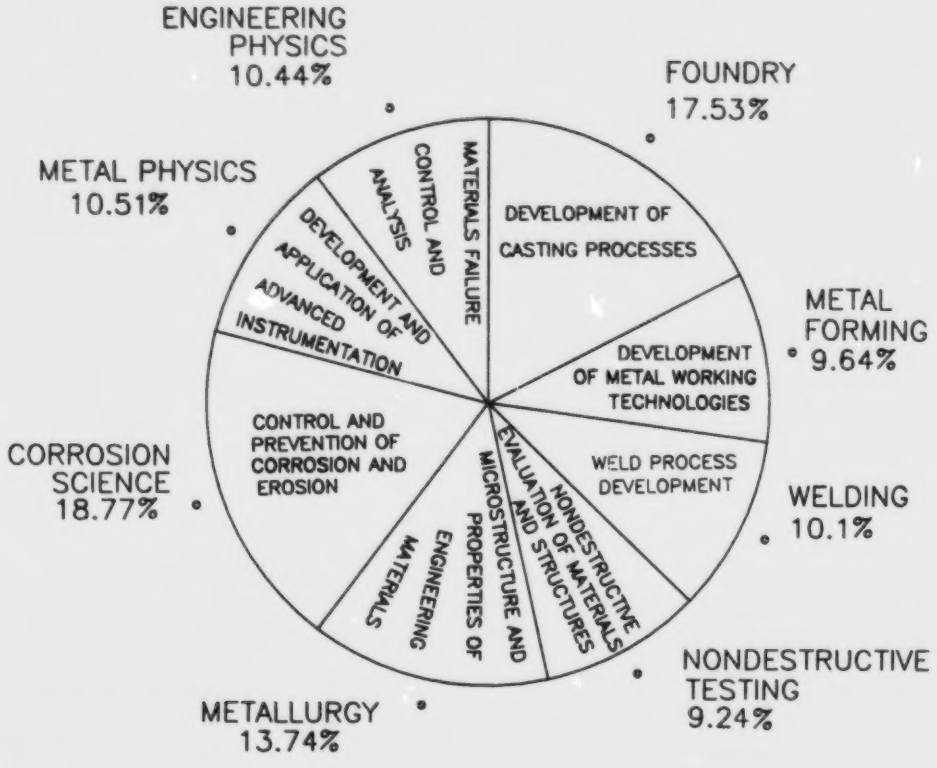
MICROMEDIA

PMRL 86 – 40 (TR)

The Physical Metallurgy Research Laboratories (PMRL) have a staff of about 135. Of these about 55 are scientists or engineers and 50 are technical support staff. In addition, throughout the year PMRL has about 25 visiting staff composed of students, post-doctoral fellows and workers from industry. PMRL is divided into two laboratories of approximately equal size, the Metals Processing Laboratory and the Metals Development Laboratory. In turn, each laboratory is divided into several sections.

ALLOCATION OF PMRL'S RESOURCES 1985-86

(Expressed as percentage dollar expenditure - excluding contract dollars)



HIGHLIGHTS OF PMRL'S RESEARCH PROGRAM

In its second year of transCanada operations, the Mobile Foundry Laboratory (MFL) visited a further 24 companies to conclude a highly successful technology transfer program. An economic impact study of 46 foundry clients reflected this success by showing production savings of ~ $1 M per year and 23 new technical jobs were created. The MFL service itself will continue under the CANMET monitored auspices of the Association of Provincial Research Organizations.

Thin-wall (5-12 mm) cast iron engine products have been produced in a tilt mould simulation of low pressure disposable mould die casting.

Successful field trials of chromium carbide coated (CANMETcoat) digger teeth have been completed and a pilot production run has been planned.

Throughout the past year, the effects of alloying, deformation and cooling rate - important steelmaking parameters in determining the properties of the final product - were studied with the quench deformation dilatometer. In particular, the accelerated cooling of a number of microalloyed steels was investigated. The results of this work were found to correlate well with the results of plate rolling trials on the PMRL experimental rolling mill. The ultimate purpose of this work is to develop a data bank embracing many steels, from which, models can be developed to help tailor steels more precisely to needs.

The advantages of cam plastometry simulation of hot forming parameters were neatly illustrated in work detailing thermal and strain effects on A and F grain refinement in Ti-N-V steels, which study was subsequently applied in seamless tube production.

Two things emerge from the work done to date to improve the wear resistance of rails. First, inclusions of the manganese sulphide type induce wear, whereas oxide inclusions have little effect. Second, although to a point wear resistance increases with increasing hardness, for a given hardness, steels with microstructures of the bainite type are more prone to cracking than rails with pearlite microstructures.

The past year saw PMRL's program on rapid solidification processing firmly established. Work on four exploratory contracts was carried out essentially to completion. In house, the corrosion resistance of rapidly solidified (RS) aluminum bronzes containing iron was found to be greatly superior to the corrosion resistance of conventional sand-cast alloys of similar composition. The difference is thought to arise from the greater homogeneity of the RS material.

A major program continues in house and under contract to enable the estimation of the fatigue lives of the nodes of offshore rigs and platforms.

The research performed in PMRL complements in ways of interest to Canada, a large program coordinated by the European Steel and Coal Community. A complete exchange of information takes place between the Canadian and European programs. A highlight from the in-house Canadian work is the effect of plate thickness on the fatigue life of welded T-joints in both air and sea water.

Although modern structural grades of steel of a kind used for making critical members of offshore structures are cleaner and, therefore, tougher than they once were, nevertheless, they are still subject to brittle fracture in ways that are not yet fully understood. For example, for a given steel grade and acuity of stress concentrator, plate thickness and temperature play a role. It is important for regulatory as well as industrial purposes that there is a public awareness of the emerging knowledge on brittle fracture.

An evaluation of the fracture toughness of weld consumables for offshore and Arctic applications has shown available shielded-metal-arc welding (SMAW) and flux-cored arc welding (FCAW) electrodes unsuitable or marginal in performance at -30°C. By contrast Ti-B containing low Ni wire flux combinations gave good -30°C CTOD and Charpy values in SAW welds.

In the past year a second special purpose corrosion "test-tank" was commissioned for PMRL's comprehensive program on the weld-related corrosion of ship plates. This program has three main parts. The first is an exploratory project, 50:50 cost shared with Algoma, to evaluate the corrosion behaviour of several steels, welded with a number of rods, at three different levels of heat input. The corrosion behaviour was determined in PMRL and the welding was performed by AMCA International. The second part is a contract funded to AMCA International by Canadian Coast Guard in which weld repairs are simulated on ships plate of three grades with five different welding rods at two heat inputs. The corrosion behaviour of the "repair" welds, characterized by electrochemical testing carried out by AMCA, is being correlated by PMRL with the results of tank tests. Finally, a three year study contracted to the Welding Institute of Canada is being funded equally by CANMET, Stelco, Algoma Steel and Nippon Steel. This work focuses on the corrosion behaviour of the heat-affected zone of welds and progress is monitored by a panel drawn from the four sponsors of the research.

Simulation of heat-affected-zone (HAZ) microstructure and properties has continued by a PMRL scientist seconded to Japan, where his work embraced control-rolled, on-line accelerated cooled (CROLAC) steel grades with good HAZ toughness at high (3.5 to 10 kJ/mm) heat inputs. Gleeble simulation of strand-casting thermal history produced ductility/temperature characterization of a number of existing and proposed microalloy steels.

In a PMRL-run national program on overlay disbonding, electroslag deposits have been autoclave tested in hydrogen and have shown de-cohesion of the stainless overlay. The work will continue to relate disbonding to fabrication and operational parameters.

Research on stress analysis using the hole drilling method to elucidate stress gradients at the surface of specimens has been completed. This method is useful because there are circumstances in which it is acceptable to drill a small hole in a structural member to a shallow depth particularly, if, for example, the hole can be subsequently welded up, or machined out. As a result of this work, it is now possible to calculate stresses from surface strain relaxations measured with strain gauges in a manner corrected for a finite section thickness.

The first commercial prototype of the CANMET portable X-ray stress diffractometer performed satisfactorily in laboratory tests performed by Ontario Hydro Research. Field trials, to be conducted at one or other of the provincial utility's installations, are scheduled for an early start in the 1986-87 financial year.

A non-contact laser-induced ultrasonic inspection procedure has been demonstrated for applications at elevated temperatures. The technique is essentially surface insensitive and may be developed for both defect detection and/or material characterization, e.g. austenite/ferrite proportions. A 3D defect imaging system originating at PMRL has become the subject of a substantial development grant awarded to Techno-Scientific of Toronto. In parallel with this, an acoustic emission system for crack or leak detection has been tested during thick-plate SMA welding and gas cylinder performance monitoring.

The electron microprobe is useful for making in situ analyses on small particles embedded in matrixes of other substances. It operates by exciting and identifying characteristic X-rays from a specimen. However, accurate quantitative analyses are complicated by the need to determine correctly the relative intensities of the X-rays emitted by the sample. Until a PMRL scientist developed a new mathematical treatment, scientists in the microprobe community processed their measured data incorrectly. In recent work, the same scientist has extended his approach to specimens that are stratified or layered. To be able to make accurate analyses on specimens carrying thin films is very important in this age of microelectronics.

In producing certain microelectronic devices, chemical vapour deposition of thin silicon films is an important process. In the past, studies of these films by analytical electron microscopy have indicated the atomic structure to be hexagonal rather than cubic. However, careful work at PMRL has shown that silicon films can contain high densities of micro-twins which affect the X-ray patterns diffracted by the films sufficiently to give the misleading impression that the crystal structure is hexagonal rather than cubic.

During the past year, the series of ten, 1000 h elevated temperature corrosion/erosion tests on in-bed heat transfer tubes have been completed at Point Tupper, Nova Scotia. The enormous amount of data on the multi-alloy tubes, generated by the test program, continues to be collated by PMRL. The performance of the various alloy sections from which each of the tubes in the combustor was made up is evaluated in a phenomenological manner. The salient fact that emerges is that the erosion component of the alloy degradation process is much larger than was anticipated.

The gradual depletion of sulphur-free (sweet) petroleum deposits and their replacement by sour deposits has brought about an accompanying increase in corrosion problems. In addition there has been an increase in the use of enhanced oil recovery techniques which can subject linepipe steels to combinations of carbon dioxide, hydrogen sulphide and moisture at elevated temperatures and pressures. To meet this growing challenge, PMRL is cooperating with Algoma Steel Corporation, Canada's producer of downhole, high strength seamless tubular products in a program to develop a new generation of clean steels with enhanced resistance to sulphide stress cracking. As a part of this program, PMRL is evaluating a new slow strain rate test which takes 2-3 days to complete and could replace the current standard test which takes 30 days.

GRANDES LIGNES DU PROGRAMME DE RECHERCHE DES LRMP

Au cours de sa deuxième année d'activités à la grandeur du Canada, le Laboratoire de fonderie mobile (LFM) a visité 24 sociétés additionnelles pour compléter un programme de transfert de la technologie qui a connu un très grand succès. Une étude des répercussions économiques portant sur 46 fonderies visitées a réflété ce succès : elle a montré que les économies de production ont atteint environ 1 million de dollars par année et que 23 nouveaux postes de techniciens ont été créés. Les services du LFM vont continuer à être offerts sous les auspices de l'Association des organisations provinciales de recherche et seront contrôlés par le CANMET.

Des pièces de moteur en fonte à parois minces (5 à 12 mm) ont été fabriquées dans une étude de simulation de la coulée en moule jetable à basse pression avec un moule basculant.

On a terminé avec succès des essais sur le terrain de dents d'excavatrice revêtues de carbure de chrome (revêtement CANMET), et on a prévu un cycle de production pilote.

Tout au long de l'année écoulée, on a étudié, avec le dilatomètre de déformation à la trempe, les effets du procédé d'alliage, de la déformation et de la vitesse de refroidissement, qui sont des paramètres de fabrication de l'acier jouant un rôle important dans les propriétés du produit final. On a notamment étudié le refroidissement accéléré d'un certain nombre d'aciers micro-alliés. On a trouvé une bonne corrélation entre les résultats de cette étude et ceux des essais de laminage de plaques effectués sur le laminoir expérimental des LRMP. Le but final de ces travaux est de préparer une banque de données relatives à un grand nombre d'aciers, à partir de laquelle on pourra élaborer des modèles qui aideront à fabriquer des aciers dont les caractéristiques seront mieux adaptées aux besoins.

Les avantages de la simulation, au moyen du plastomètre à came, des paramètres de formage à chaud ont été nettement démontrés dans une étude des effets de la chaleur et de la déformation sur l'affinage des grains A et F dans des aciers au Ti-N-V. Cette étude a par la suite été appliquée à la production de tubes sans soudure.

Deux conclusions peuvent être tirées des travaux effectués jusqu'à maintenant en vue d'accroître la résistance à l'usure des rails. Premièrement, les inclusions du type sulfure de manganèse provoquent l'usure, tandis que les inclusions du type oxyde ont peu d'effets. Deuxièmement, bien que dans une certaine mesure la résistance à l'usure des rails augmente avec leur dureté, pour une dureté donnée, les aciers ayant des microstructures bainitiques sont plus sujets à la fissuration que les aciers ayant des microstructures perlitiques.

Au cours de l'année dernière, le programme de traitement par solidification rapide des LRMP a été solidement établi. Les travaux relatifs à quatre contrats d'études exploratoires ont été à toutes fins pratiques réalisés. Dans des études internes, on a trouvé que la résistance à la corrosion des bronzes d'aluminium solidifiés rapidement (SR) et contenant du fer était beaucoup plus élevée que la résistance la corrosion des alliages classiques de composition similaire coulés en sable. On croit que la différence est due à la plus grande homogénéité des alliages solidifiés rapidement.

On poursuit un important programme de travaux internes et de travaux réalisés à contrat en vue de l'estimation de la longévité à la fatigue des noeuds d'installations de forage et de plates-formes océaniques. La recherche effectuée aux LRMP complète, dans des secteurs d'intérêt pour le Canada, un vaste programme coordonné par la communauté européenne de l'acier et du charbon. Il y a échange complet d'informations entre le programme canadien et le programme européen. L'un des éléments importants des travaux internes réalisés dans le cadre du programme canadien est l'étude des effets de l'épaisseur des plaques sur la longévité à la fatigue des joints soudés en ▲ dans l'air et dans l'eau de mer.

Bien que les aciers de construction modernes du type utilisé pour la fabrication des membres critiques de structures océaniques soient plus propres et, par conséquent, plus résistants qu'auparavant, ils sont encore sujets à la rupture fragile suivant des mécanismes qu'on ne comprend pas encore complètement. Par exemple, pour une nuance d'acier donnée et une certaine intensité de concentration des contraintes, l'épaisseur et la température de la plaque d'acier influent sur la rupture fragile. Il est important, à des fins de réglementation de même qu'à des fins industrielles, que le public soit sensibilisé aux nouvelles connaissances sur la rupture fragile.

Une évaluation de la résistance à la rupture des éléments de soudage fusibles destinés à des applications en mer et dans l'Arctique a montré que les électrodes disponibles pour le soudage à l'arc métallique avec protection et le soudage à l'arc aux électrodes fourrées de flux sont inadéquates ou ont un rendement marginal à -30 °C. Par contre, les combinaisons fil-flux de Ti-B contenant une faible concentration de Ni ont donné de bons résultats dans les essais de déplacement de l'ouverture de la pointe de fissure et les essais de Charpy à -30 °C dans des soudures réalisées à l'arc sous flux.

Au cours de la dernière année, on a mis en service un deuxième "bassin" pour les essais de corrosion dans le cadre du vaste programme des LRMP sur la

corrosion liée aux soudures des plaques pour navires. Ce programme comprend trois parties principales. La première partie est un projet d'étude exploratoire, dont les coûts sont partagés à parts égales avec la société Algoma, en vue d'évaluer les caractéristiques de corrosion de plusieurs aciers, soudés en utilisant plusieurs sortes de baguettes, à trois degrés différents d'amenée de chaleur. Les caractéristiques de corrosion ont été déterminées dans les LRMP et le soudage a été réalisé par AMCA International. La deuxième partie du programme est un contrat accordé à AMCA International par la Garde côtière canadienne; il s'agit de simuler des réparations par soudage sur des plaques de trois nuances pour navires en utilisant cinq sortes de baguettes à souder et deux degrés d'amenée de chaleur. Les LRMP établissent présentement une correspondance entre les caractéristiques de corrosion des soudures "de réparation", déterminées par des essais électrochimiques effectués par AMCA, et les résultats des essais de corrosion effectués dans le bassin. Enfin, une étude de trois ans confiée à contrat à l'Institut de soudage du Canada est financée à parts égales par le CANMET, la Stelco, l'Algoma Steel et la Nippon Steel. Cette étude porte sur les caractéristiques de corrosion de la zone affectée par la chaleur, et les progrès sont surveillés par un comité formé de représentants des quatre organismes qui financent le projet.

Les travaux de simulation de la microstructure et des propriétés de la zone affectée par la chaleur ont été poursuivis par un scientifique des LRMP détaché au Japon, où il étudie des nuances d'aciers soumis à un refroidissement accéléré en direct et à un laminage contrôlé (RADLC) dont la zone affectée par la chaleur a une bonne ténacité à des amenées de chaleur élevées (3,5 à 10 kJ/mm). La simulation sur le Gleeble des phénomènes thermiques de la coulée continue a permis de caractériser la relation ductilité/température d'un certain nombre d'aciers microalliés existants et proposés.

Dans le cadre d'un programme national réalisé par les LRMP sur le décollage des recouvrements, des dépôts de fusion sous laitier électroconducteur ont été soumis à des essais dans un autoclave en présence d'hydrogène, et on a observé une perte de cohésion du recouvrement inoxydable. On poursuivra les travaux en vue d'établir le lien entre le décollage et les paramètres de fabrication et de fonctionnement.

On a terminé l'analyse, par la méthode des trous, des gradients de contrainte à la surface des échantillons. Cette méthode est utilisable lorsqu'on peut creuser un petit trou peu profond dans un membre de structure et, particulièrement, lorsqu'on peut par la suite éliminer le trou par soudage ou par usinage. Grâce à ces travaux, on peut maintenant calculer les contraintes à partir de mesures extensométriques de relaxation des déformations superficielles, corrigées pour une épaisseur de section finie.

Le premier prototype commercial du diffractomètre X de contraintes portatif du CANMET a donné des résultats satisfaisants dans des essais de laboratoire effectués par l'Ontario Hydro Research. On prévoit que les essais sur le terrain, qui seront réalisés à l'une ou l'autre des installations de la compagnie d'électricité provinciale, débuteront au cours de l'année financière 1986-87.

On a fait la démonstration d'une méthode d'inspection ultrasonique à laser sans contact utilisable à températures élevées. La technique est à toutes fins pratiques insensible à l'état de la surface, et elle peut être mise au point pour la détection des défauts aussi bien pour la caractérisation des matériaux, p. ex. pour la détermination des proportions d'austénite et de ferrite. Une importante subvention de développement a été accordée à la société Techno-Scientific de Toronto pour des travaux sur un système de visualisation tridimensionnelle des défauts qui a été créé aux LRMP. Parallèlement à ces travaux, on a effectué des essais sur un système d'émission acoustique pour la détection des fissures ou des fuites pendant le soudage de plaques épaisses à l'arc métallique avec protection et pour le contrôle des bouteilles de gaz.

La microsonde électronique est pratique pour la réalisation d'analyses in situ portant sur de petites particules incluses dans des matrices d'autres substances. Son principe de fonctionnement consiste à exciter un échantillon et à identifier ses rayons X caractéristiques. Cependant, des analyses quantitatives précises sont difficiles à réaliser car il faut déterminer avec exactitude l'intensités relative des rayons X émis par l'échantillon. Avant qu'un scientifique des LRMP n'ait élaboré un nouveau traitement mathématique, le traitement des mesures faites à la microsonde était incorrect. Dans des travaux récents, le même scientifique a étendu son traitement aux échantillons stratifiés ou en couches. Il est très important dans la micro-électronique d'aujourd'hui que les analyses d'échantillons comportant de minces couches soient précises.

Dans la fabrication de certains dispositifs microélectroniques, la production de minces couches de silicium par dépôt chimique en phase vapeur est un procédé important. Par le passé, les études de ces couches par microscopie électronique analytique ont montré que leur structure atomique est hexagonale plutôt que cubique. Cependant, des travaux minutieux effectués aux LRMP ont montré que des couches de silicium peuvent avoir une densité élevée de micro-cristaux jumelés qui influent suffisamment sur les figures de diffraction des rayons X produites par ces couches pour donner la fausse impression que la structure cristalline est hexagonale plutôt que cubique.

Au cours de la dernière année, on a terminé, à Point Tupper (Nouvelle-Écosse), la série de dix essais de corrosion/érosion à température élevée, d'une durée de 1000 h, portant sur les tubes de transfert de chaleur dans un lit fluidisé. Les LRMP continuent de classer la quantité énorme de données sur les tubes multi-alliés produites dans le cadre du programme d'essais. Le rendement des différents alliages qui constituent chacun des

tubes de la chambre de combustion est évalué de façon phénoménologique. Le fait le plus marquant qui ressort de cette étude est que la composante érosion du processus de dégradation des alliages est beaucoup plus importante que prévue.

L'appauvrissement graduel des gisements de pétrole non sulfuré (non corrosif) et leur remplacement par des gisements sulfurés font que les problèmes de corrosion se multiplient. De plus, on utilise davantage des techniques de récupération accrue du pétrole dans lesquelles les aciers pour pipelines peuvent être exposés à des combinaisons de dixoyde de carbone, de sulfure d'hydrogène et d'humidité à des températures et pressions élevées. Afin de faire face à ce problème grandissant, les LRMP travaillent en collaboration avec l'Algoma Steel Corporation, le fabricant canadien de produits tubulaires sans soudure, de grande résistance, utilisables dans les puits de forage, à la réalisation d'un programme visant à mettre au point une nouvelle génération d'aciers propres ayant une résistance accrue à la fissuration sous contrainte en présence de sulfure. Dans le cadre de ce programme, les LRMP évaluent présentement un nouvel essai de déformation lente qui dure de 2 à 3 jours et qui pourrait remplacer l'essai standard actuel qui dure 30 jours.

PATENTS AND SPECIAL AWARDS

J.D. Boyd was elected a Fellow of the American Society for Metals in June 1985.

J-P. Monchalin was granted US Patent 586323 for a "Method and device for determining properties of materials from a measurement of ultrasonic absorption".

R.H. Packwood was chosen as the tour speaker for the Microbeam Analysis Society in the Spring of 1985.

E.I. Szabo and L.V. Whiting were granted US Patent 4509983 for "A method of manufacturing a foundry mould mix containing binder components and mould binder components therefore".

J.J.M. Too was invited to give a lecture series at the Institute of Atomic Energy, Beijing, China in the Fall of 1985.

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METALS DEVELOPMENT LABORATORY

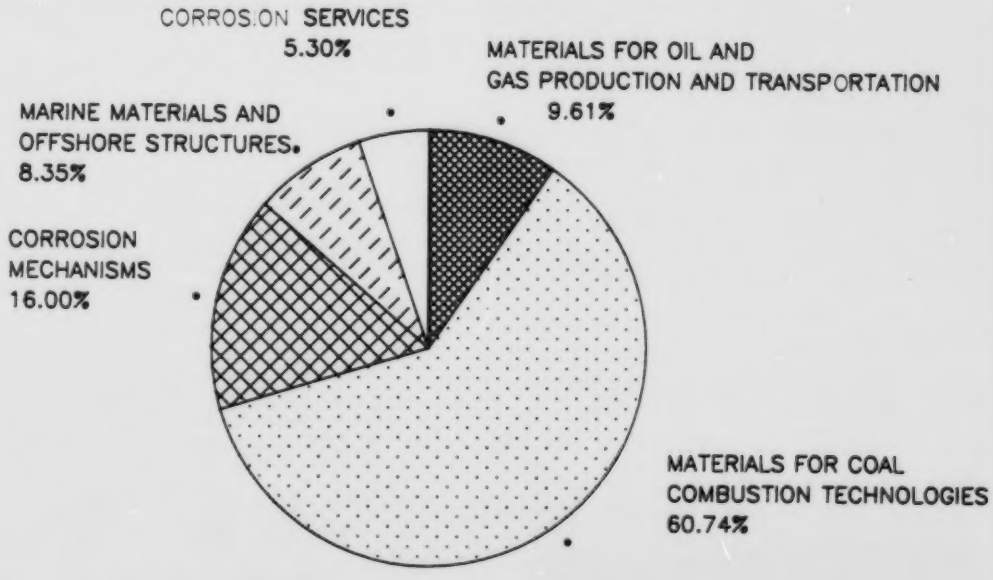
MANAGER D.W.G. WHITE 993-7074

CORROSION SCIENCE SECTION

SECTION HEAD **R.W. REVIE** **993-4527**

CONTROL AND PREVENTION OF CORROSION & EROSION

(EXPRESSED AS PERCENTAGE DOLLAR EXPENDITURE)



(Excluding contract dollars)

Project	Lead Scientist	
MATERIALS FOR OIL AND GAS PRODUCTION AND TRANSPORTATION	R.W. REVIE	993-4527
MATERIALS FOR COAL COMBUSTION TECHNOLOGIES	J.B. GILMOUR	996-4369
CORROSION MECHANISMS	R.W. REVIE	993-4527
MARINE MATERIALS AND OFFSHORE STRUCTURES	R.J. BRIGHAM	993-4527
CORROSION SERVICES	R.W. REVIE	993-4527

The overall objective of the Corrosion Science Section is to develop methodology for analyzing, preventing, controlling, monitoring and evaluating degradation by corrosion or erosion. The research carried out in pursuit of this objective is summarized in the following text.

CORROSION MECHANISMS

In studies of the localized corrosion of stainless steels, the emphasis has shifted from initiation of the process to the kinetics of its spread. The rate of pit growth as a function of alloy chemistry and exposure temperature was investigated in an attempt to predict lifetimes for engineering components. The rate of growth of individual pits was found to follow a $t^{1/3}$ rate law indicating the process to be under cathodic control.

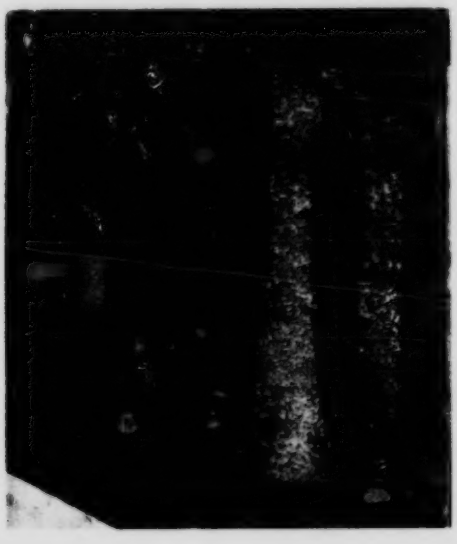
Inhibitor formulations consisting of molybdate or tungstate in combination with reagents such as phosphate or nitrite have been found to be very effective in inhibiting corrosion more than 95% in coal-water slurries containing chloride and sulphate. Surface analysis by electron microprobe, XPS, and AES techniques indicates that the protective films consist of molybdenum trioxide with FeOOH and tungsten trioxide with iron oxide.

MATERIALS FOR OIL AND GAS PRODUCTION AND TRANSPORTATION

Corrosion Performance of Sour Service Seamless Tubing

Samples of Algoma sour service C-90 seamless tubing received in the "as-quenched" condition were tempered at 6 temperatures from 610° to 780°C. The National Association of Corrosion Engineers (NACE) tensile-bar test (TM-01-77) together with the slow strain rate technique (SSRT) were used to evaluate the sulfide-stress-cracking (SSC) resistance of the tempered steels. The maximum SSC threshold stress (NACE test) was 662 MPa for a steel tempered at 715°C to a yield strength of 690 MPa. Normalized percentage reduction in area (SSRT) correlated well with the threshold stresses of the 6 tempered steels. The SSRT is a rapid method of determining SSC resistance compared with the NACE test. The maximum test time of the SSRT was 67 h compared with 720 h for the NACE test. Thus, to determine SSC-resistance of low-alloy steels by the SSRT saves considerable time.

Research is in progress to help develop a high-strength sour-service oil-country tubular steel.



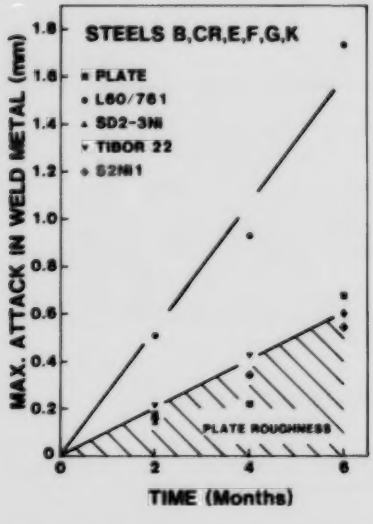
The CANMET free corrosion "tank testing" facility

MARINE MATERIALS

Weld-Related Corrosion of Hulls of Ice-Breaking Ships

The objective this work is to study the weld-related corrosion of ice-breaking ships.

An integrated program of in-house and contract research has proceeded on schedule. Results of electrochemical corrosion tests completed in the course of a cost-shared contract with a Canadian steel manufacturer correlate well with in-house free-corrosion tests which are nearing completion. Complementary work in cooperation with the Canadian Coast Guard has produced preliminary data. It is now clear that a number of shielded-metal-arc and submerged-arc-welding consumables can be chosen which minimize or eliminate weld-metal corrosion whereas the problem of heat-affected-zone attack can be controlled through modification of the steel-plate chemistry.



Kinetics of weld metal corrosion of four shielded-metal-arc welding electrodes in combination with six C-Mn steels exposed for six months in the CANMET free corrosion "tank test".

MATERIALS FOR COAL COMBUSTION TECHNOLOGIES

Performance Evaluation of Heat Transfer Tube Alloys in the EMR-NSPC Fluidized-Bed Combustor.

The main objective of this EMR funded (Coal Division) project is to provide long-term data on the corrosion/erosion behaviour of alloys used for in-bed heat transfer tubes in fluidized-bed combustors burning high-sulphur coal. Fluidized-bed combustion offers a means of burning coal to produce electricity while restricting the emission of SO_2 and NO_x to within environmentally acceptable limits. The pilot plant, operated by the Nova Scotia Power Corporation, successfully completed a total experimental program of 11 000 h on July 29, 1986, and provided PMRL with over 800 specimens of ferritic and austenitic alloys exposed at temperatures from 450° to 850°C for periods of 1 000 to 10 000 h. An international workshop (sponsored by the Electric Power Research Institute of Palo Alto, CA) on materials in fluidized-bed combustors was held at Point Tupper at the same time as the combustor reached the 11 000 h mark. PMRL scientists played a major role in this workshop.

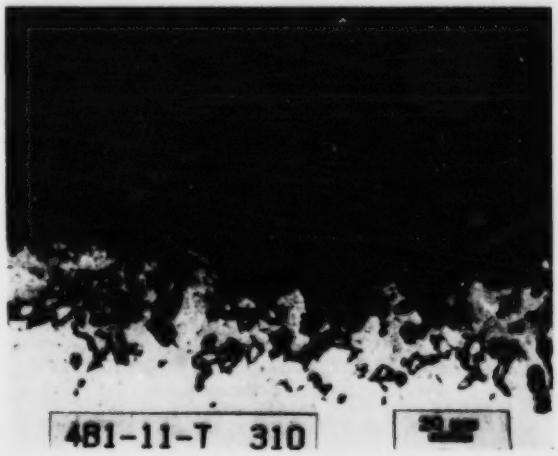
Analysis of the exposed specimens proceeded throughout the rest of the fiscal year; approximately half the 400 specimens removed in August were analyzed by PMRL staff and half by the Ontario Research Foundation on contract to PMRL. The results of the 9 000 and 10 000 h specimens tend to confirm the results obtained in the earlier and shorter exposures, namely that only T91 of the ferritic alloys and 310 and 347H of the austenitic alloys had acceptable metal wastage rates. The erosive conditions in the Point Tupper combustor were very severe and all the alloys exposed suffered high erosion rates in some locations. However, corrosion does not appear to be as serious a problem as previously thought, and no evidence of true breakaway corrosion was found.

Detailed analysis of the specimens is continuing at PMRL. In addition, selected specimens have been supplied to researchers at the Argonne National Laboratory and at the Lawrence Berkeley Laboratory in the USA who are cooperating with PMRL scientists on certain aspects of the analyses.

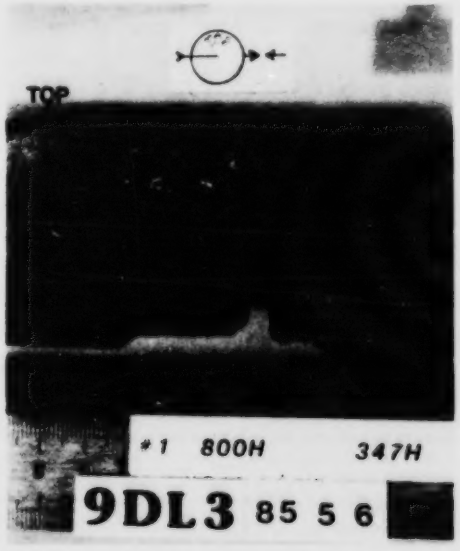
Stress-Rupture Properties of Materials in Coal Conversion Systems

The purpose of this work, performed under contract, has been to evaluate the effects of simulated fluidized-bed coal combustion on the stress-rupture properties of materials for heat exchanger tubes and in-bed hardware. Testing was carried out at 800° and 900°C in a simulated combustion environment of low oxygen and high sulphur potential both in the presence and absence of simulated bed deposit. Two deposits were used, one a mixture of $CaSO_4$ and CaO, the other, actual fluidized-bed combustor bed material. Stress-rupture curves were determined for stainless steel types 310 and 347H, alloy HK40 and Incoloy 800H for about 1000 h.

No definite interplay between corrosion and deformation/rupture behaviour was established. Instances of severe corrosion occurred, but failures did not appear to be corrosion-related. Temperature cycling gave rise to much more severe corrosion and a greater effect on stress-rupture properties than did long-term tests under steady conditions. The work has been completed and the final report issued.



Photomicrograph showing deposit/scale (mainly iron oxide), sub-scale (mainly chromium oxide and sulphide) and chromium sulphide intrusions on 310 stainless steel test sample after 8000 h exposure in Nova Scotia Power Corporation's fluidized-bed coal combustor.



Catastrophic sulphidation/oxidation experienced by an Incoloy 800 H test sample during exposure for 4000 h in Nova Scotia Power Corporation's fluidized-bed coal combustor.

Sulphur solubility and diffusivity in Cr_2O_3

This project, carried out under contract, is designed to generate useful thermodynamic and kinetic data to elucidate the degradation mechanism of the Cr_2O_3 - forming stainless steels in environments simulating the combustion of S-rich coals.

Cold and hot pressed Cr_2O_3 pellets, with varying degrees of porosity, were equilibrated in $CO/CO_2/SO_2$ gas mixtures. The equilibrium oxygen and sulphur potentials in these gas mixtures were computed electronically. Several techniques were used to determine the amount of dissolved sulphur including, infra-red spectroscopy and proton and neutron activation analyses.

Sulphur solubility in Cr_2O_3 was found to be quite small, 10-90 ppm. The results confirm that the principal mechanism by which Cr_2O_3 scale-forming alloys degrade involves the transport of sulphur along grain boundaries and other structural imperfections.

Alloy Oxidation Behaviour Under Thermal Cycling

The effect of minor additions (<1 wt %) of Hf, Zr and Ca to an Fe-10 wt % Al alloy on isothermal and thermal cyclic oxidation was studied. Both Hf and Zr increased the isothermal oxidation rate in proportion to their concentration; however, they significantly improve the adhesion of Al_2O_3 scale and tne performance of the alloy under thermal cycling. The addition of Ca reduced the isothermal oxidation rate slightly and improved resistance to thermal cycling, but to a lesser extent than Hf and Zr. Surface treatment techniques for incorporating Ca and other beneficial elements in commercial alloys are under investigation.

ADVANCED MATERIALS

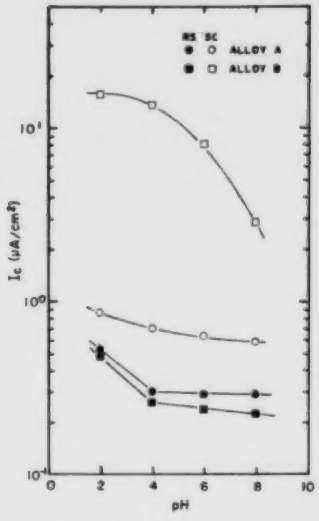
Corrosion Properties of Rapidly Solidified Fe-Al Bronzes

The corrosion behaviour of several rapidly-solidified Fe-Al bronzes was studied by electrochemical measurements. Microstructural effects could be separated from the compositional effects by comparative studies on sand-cast alloys of the same composition.

The results of preliminary work demonstrate that rapid solidification improves corrosion resistance both in Cl^--free and Cl^--containing environments in the range of pH from 2 to 8. It has been shown that microstructural refinement as well as extension of solid solubility of Fe achieved by rapid solidification play a role in improving the corrosion resistance of Fe-Al bronzes.

Influence of Surface Modification on Alloy Oxidation Behaviour

The purpose of this research, carried out under contract, is to explore the potential of ion-beam mixing to improve high temperature oxidation behaviour.



Variation of corrosion rate I_c with pH for two alloys A and B in a 0.15N Na_2SO_4 test solution. Rapidly solidified (RS) alloys are compared with alloys sand cast and annealed for 6h at 973 K (SC).

During this FY, work concentrated on the effect of Al implantation in pure Fe and dilute Fe-Al alloys. Single and multiple implants were carried out at energies of 30 ~ 100 kV and doses of 5 x 10^{15} ~ 5 x 10^{17} ions/cm^2. Oxidation behaviour was studied over a temperature range of 600-900°C at a pressure of ~100 to 200 torr oxygen.

Some of these treatments resulted in a modest improvement in the oxidation resistance (up to a factor of x3) as a duplex Fe_2O_3 developed on the implanted alloy rather than the $Fe_2O_3/(FeAl)_3O_4$ scale on top of a $(FeAl)_3O_4/Al_2O_3$ subscale which forms on the untreated alloy. However, upon prolonged exposure, the relatively protective duplex film exhibited extensive buckling and an increasing density of thick isolated, Fe_2O_3 nodules. Implantation of Y did not result in a significant improvement in the mechanical and adhesive properties of the Fe_2O_3/Al_2O_3 film.

SYNTHESIS OF CORROSION/WEAR-RESISTANT SURFACE ALLOYS AND COATINGS
(Joint project with NRC)

The main thrust of this project is to determine the potential benefits of novel surface modification techniques, including ion implantation, laser treatment and plasma spraying, on the high temperature corrosion-wear behaviour of materials. A literature review covering this subject has been completed.

The experimental program, recently begun, has focused on the effect of laser surface melting and alloying with Cr and Al on the high temperature oxidation/erosion behaviour of ferritic steels.

The effects of such laser processing parameters as power density and interaction time on surface microstructure and composition are being studied, as is the high temperature oxidation behaviour of treated alloys.

CORROSION SERVICES

The Corrosion Science Section provides analytical services for nitrogen, oxygen and hydrogen in metals. During 1985/86, about 600 steel samples have been analyzed for oxygen and nitrogen, in support of research on clean steels and welding. About 900 samples have been analyzed for hydrogen, mainly as a service to the cooperative program between PMRL and Sysco on rail steel development.

PAPERS PUBLISHED IN OUTSIDE JOURNALS AND CONFERENCE PROCEEDINGS

(authors from the Corrosion Science Section underlined)

Brigham, R.J.
"The initiation of crevice corrosion on stainless steels"; Materials Performance; 24(12):44; 1985.

Collins, L.E., Mitrovic-Scepanovic, V. and Thompson, I.
"Rapidly solidied copper-base alloys for marine applications"; Intnl Conf on Rapidly Solidified Materials; Feb. 3-5, 1986, San Diego, CA; ASM; 435-442, 1986.

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"Selected results after 5000 hours exposure in the Canadian AFBC materials program"; Corrosion 1986; Houston, TX; National Association of Corrosion Engineers; 15, 1986.

Packwood, R.H., Sastri, V.S. and Brown, J.R.
"Surface quantification in the electron microprobe"; Microbeam Analysis; 97; 1985.

Sastri, V.S., McDonnell, D.B., Tjan, C. and Bednar, J.S.
"Studies on the analysis of hydrogen in high-strength steels"; Metallurgical Trans; 16A:1694; 1985.

Sastri, V.S., Packwood, R.H., Moore, V.E. and Bednar, J.S.
"Surface analysis in studying corrosion inhibition mechanisms"; 6th European Conference on Corrosion Inhibitors; Sept. 16, 1985; Ferrara, Italy; 1985.

AVAILABLE PMRL REPORTS

MRP/PMRL 84-70(OP-J) Gilmour, J.B. "Corrosion of a municipal water distribution system".

ERP/PMRL 84-74(OP-J) Gilmour, J.B., Briggs, D. and Hindam, H. "Preliminary results of the Canadian AFBC materials test".

MRP/PMRL 85-6(OP-J) Sastri, V.S., Packwood, R.H., Moore ,V.E. andBednar, J. "Surface analysis in studying corrosion inhibition mechanisms".

MRP/PMRL 85-10(OP-J) Packwood, R., Sastri, V.S. and Brown, J.D. "Surface quantitation in the electron microprobe".

PMRL 85-49(OP-J) Gilmour, J.B., Hindam, H.M., Lui, A.W., Briggs, D. and Knight, R.F., "The point tupper AFBC corrosion program: Selected results".

PMRL 85-50(OP-J) Collins, L.E., Mitrovic-Scepanovic, V. and Thompson, I. "Rapidly solidified copper base alloys for marine application".

ERP/PMRL 84-10(J) Biefer, G. and Fichera, M. "Sulphide stress cracking failures in the grissly pipeline".

PMRL 85-53(J) Hindam, H. "Materials behaviour in fluidized bed combustors: Problems and research opportunities".

ERP/PMRL 85-1(J) Hoey, C.R. and Ramsingh, R.R. "Cracking rate of grade 483 linepipe steel in Co_3/HCO_3 environment during SCC by the slow rate technique".

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(presenting author underlined)

Gilmour, J.B.
The EMR/NSPC AFBC materials program at Point Tupper; Dept. of Chem Eng, Queens University, Kingston, Ont.; May 15, 1985.

Gilmour, J.B., Hindam, H., Lui, A.W., Briggs, D.C. and Knight, R.F.
The Point Tupper AFBC corrosion program: selected results; EPRI sponsored Workshop on Materials for Fluidized Bed Comustors; Point Tupper, N.S.; July 29, 1985.

Gilmour, J.B., Hindam, H., Briggs, D.C., Lui, A.W. and Packwood, R.
Materials degradation in the Point Tupper atmospheric fluidized bed combustor; Electrochemical Society Symp on Corrosion and Applied Electrochemistry; Halifax, N.S.; Oct. 11, 1985.

Gilmour, J.B., Hindam, H., Lui, A.W., Briggs, D.C. and Knight, R.F.
"Selected results after 5000 hours exposure in the Canadian AFBC materials program"; Corrosion 1986; Houston, TX; March 18, 1986.

R.W. Revie and G.R. Hoey
Proposal: "Determination of minimum dissolved hydrogen concentration causing stepwise cracking of linepipe steels"; Meeting of the CSA Sour Gas Corrosion Task Force; Toronto, Sept. 10, 1985.

R.W. Revie
Presentation on Corrosion R & D at CANMET; Intnl Development Research Centre, Corrosion Research Workshop; Hamilton, Sept. 16-17, 1985.

Hoey, G.R.
"Hydrogen sulfide cracking of linepipes and oil country tubular steels"; NACE Eastern Region Conf; Montreal, Nov. 14, 1985.

Hindam, H., J.-J. Hechler and Whittle, D.P.
"Effect of oxygen-active elements on scale adhesion"; Poster Presentation; Gordon Research Conf; New London, NH, July 22-26, 1985.

Hindam, H.
"Materials behaviour in fluidized bed combustors: problems and research opportunities"; Workshop on materials issues in fluidized bed combustors; Port Hawksbury, N.S., July 29-31, 1985.

GRANT AND MONITORING ACTIVITIES

DESIGNATED SCIENTIFIC AUTHORITIES AND LIAISON OFFICERS

SA/LO	Performer	Project
D.C. Briggs	Sherritt Gordon Research Centre	Evaluation of stress-rupture properties of stainless alloys in fluidized bed combustion environments
R.J. Brigham	Algoma Steel	Evaluation of weld zone corrosion of shipbuilding steel plates for use in the Arctic environment
R.J. Brigham	Welding Institute of Canada	Evaluation of steels, welding consumables and procedures for optimum corrosion behaviour in Arctic marine application
J.B. Gilmour	Ontario Research Foundation	Evaluation of corrosion of FBC heat transfer tubes
H. Hindam	École Polytechnique	Sulphur solubility and diffusivity in Cr_2O_3
H. Hindam	McMaster University	Influence of surface modification on alloy oxidation behaviour
R.W. Revie	C & M Engineering Ltd., Calgary	The effect of carbon dioxide (CO_2) on seamless and tubular goods

SA/LO	Performer	Project
R.W. Revie	Univ. of Manitoba	Evaluation of Al=Li-X ternary phase diagrams
V.S. Sastri	AMCA International, Kanata, Ontario	Characterization of surface-bound hydrogen in high-strength steels by secondary ion mass spectrometry (SIMS)

RESEARCH CONTRACT REPORTS

(In order of completion)

403902 Briggs, D.C. "Evaluation of stress-rupture properties of stainless alloys in fluidized bed combustion environments. Phase 2 report". Prepared by Sherritt Res. Centre.

403902-706502 Briggs, D.C. "Evaluation of stress-rupture properties of stainless alloys in fluidized bed combustion environments interim report for Phase 3. Parts 1 and 2 prepared by Sherritt Res. Centre, Sherritt Gordon Mines Ltd.

706504 Gilmour, J.B. "Biofouling considerations in the development of Atlantic Canada's offshorfe petroleum industry". Prepared by Fundy Isles Marine Enterprises, Ltd.

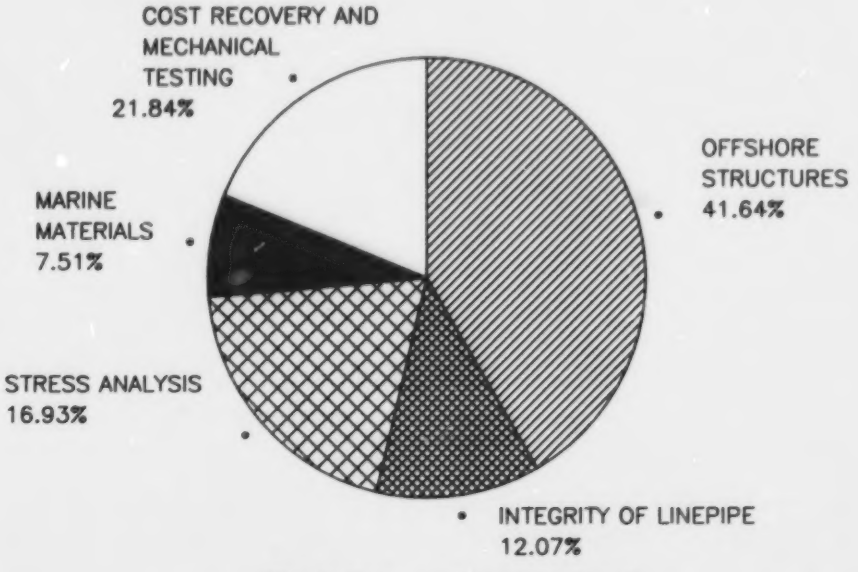
360102 Biefer, G.J. "Underground corrosion of water pipes in Canadian cities. case: The city of Calgary". Prepared by Caproco Corrosion Prev. Ltd.

ENGINEERING PHYSICS SECTION

SECTION HEAD **W.R. TYSON** **993-7103**

MATERIALS FAILURE CONTROL AND ANALYSIS

(EXPRESSED AS PERCENTAGE DOLLAR EXPENDITURE)



(Excluding contract dollars)

Project	Lead Scientist	
OFFSHORE STRUCTURES	O. VOSIKOVSKY	993-7083
INTEGRITY OF LINEPIPE	K.C. WANG	993-7104
STRESS ANALYSIS	G. ROY	993-7083
MARINE MATERIALS	W.R. TYSON	993-7103
COST RECOVERY AND MECHANICAL TESTING	W.R. TYSON	993-7103

This section is responsible for mechanical testing including, in addition to customary tensile strength and hardness measurements, evaluation of fracture resistance at low temperature, under impact or fatigue, and the determination of residual stresses by mathematical and mechanical means. There is also significant activity in failure analysis and fracture control.

A complete range of equipment is available to perform conventional mechanical tests and a specialized facility to pressurize pipe sections to study the growth of defects is in place. In addition, members of the section have recently developed equipment for corrosion fatigue testing of heavy-section welded T joints, and for elastic-plastic toughness measurement over a wide temperature range. Instrumented impact testing equipment has been acquired, and upgrading of facilities for testing heavy sections is underway.

The Engineering Physics section performs mechanical tests as a service to other sections and to industry, and participates with industry and with universities in projects that call for determining the mechanical behaviour of metals. To support this work, much of the section's effort is devoted to developing competence in new test methods and to broadening the understanding of certain variables currently at the forefront of mechanical testing research. Examples are the effects of thickness and temperature on fracture toughness and corrosion fatigue, and - as always - the effects of metallurgical microstructure on mechanical properties. In addition, a considerable effort is devoted to stress analysis by analytical, numerical, and experimental methods, so as to properly interpret the effects of specimen geometry and processing history on the mechanical behaviour of metals.

The work of the section proceeds under the following five broad categories.

FATIGUE

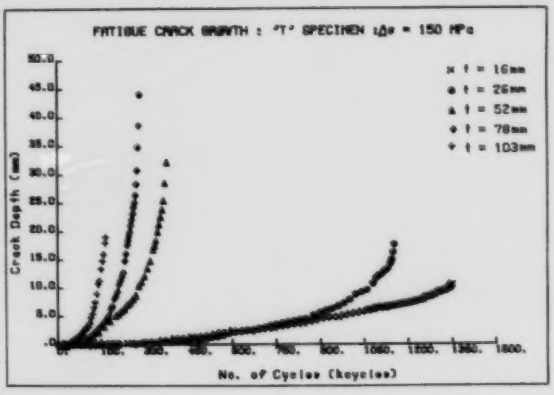
A major program is underway to evaluate the fatigue life of welded joints representative of those in steel offshore structures. In-house work complements contracts to industry and to universities designed to generate information particularly relevant to Canadian conditions. CANMET is a participating member in the offshore steels research program coordinated under the aegis of the European Coal and Steel Community. The Canadian work complements that of the Europeans.

Substantial progress has been made in experimental measurement of fatigue crack growth rates in welded plate T-joints tested in air and in sea water and in calculating of stress intensity factors as a function of load and geometry.

A fracture mechanics model for predicting the fatigue life of welded joints has been developed in cooperation with contractors. The model correctly predicts the deleterious effect of increasing plate thickness that has been demonstrated experimentally in the laboratory. In the event, the effects of thickness are stronger than assumed in current design codes.

The effect of sea water on fatigue crack growth in welded plate T-joints 26 and 78 mm thick is being measured experimentally. Results obtained to date show that fatigue lives in sea water are reduced by a factor of two to three compared with air under all conditions tested, i.e., free corrosion, optimum cathodic protection and cathodic overprotection. This means that the assumption commonly made and used in offshore fatigue design codes, that adequate cathodic protection restores fatigue life in sea water to values measured in air, may not be justified.

Experimental work on large joints, both pipe-to-plate and stiffened tubular T-joints, is being performed under contract. The results will be used to confirm or modify conclusions drawn from plate-to-plate tests.



Depth of fatigue cracks growing at the toe of welds in a plate T-joint as a function of number of cycles at a constant alternating stress range for plates of thickness varying from 16 to 103 mm. Note the pronounced decrease in fatigue life as thickness increases.

The rigs for testing large stiffened tubular joints at the University of Waterloo and Memorial University of Newfoundland have been built, and static tests to measure stress distributions in loaded tubular joints are under way.

FRACTURE MECHANICS TESTING

Toughness evaluation of modern clean steels requires elastic-plastic testing methods. PMRL has been characterizing clean steel plate for offshore applications by crack opening displacement (COD) and J integral techniques down to -160°C, with particular attention to the effect of geometry (plate thickness) on the transition temperature.

The relation between toughness and microstructure is a continuing theme in this work, in which scanning electron microscope (SEM) fractography is used routinely to characterize such micro-mechanisms of fracture as cleavage and ductile rupture.

General layout of the test rig at Waterloo University, built under CANMET contract, to load large tubular T-joints in tension and bending. The joints are fabricated by Dominion Bridge, a subsidiary of AMCA International.

In collaboration with the Metallurgy section, the effect of microstructure on the low-temperature toughness of microalloy steels is being evaluated, and also the quantitative relation between inclusion distribution and resistance to tearing (ductile) fracture.

Following an extensive series of tests to establish the variation of cleavage toughness with thickness a statistical model has been developed to interpret the results. The results are an analytic framework for predicting the fracture probability of steels. The model is being used in a separate study performed by Det norske Veritas, Calgary, of the effect of toughness variability on structural reliability.

PMRL's instrumented Charpy machine has been used to evaluate steels for Quebec Iron and Titanium, Department of National Defence and AMCA International. During the past year, an 11 kJ drop-weight machine complete with instrumented tup and anvil has been built at PMRL to test larger specimens.

FRACTURE CONTROL

The application of fracture toughness testing to prevent structural failure is a major objective of the section. It contributes to this objective in a number of ways: by performing failure analyses, by contributing to the writing of national codes and standards, and by testing structures containing known defects. For example, metallurgical analyses of ship plate failures are performed on request by Coast Guard Canada. PMRL contributes to failure analyses by evaluating the metallurgical properties of the plate and characterizing the fractures. Also, members of the Engineering Physics Section serve on a number of Canadian Standards Association (CSA) committees concerned with the selection and use of steels for structures such as pipelines and offshore production platforms. Again, PMRL maintains a pressurization facility to determine the effects of defects on the failure pressure of pipes, and to generate data for defect assessment and for setting safety standards. Current work centres on the evaluation of the effect of weld defects on the serviceability of ERW (electric-resistance-welded, actually usually induction-welded) pipe. Major pipe manufacturers and users are participating in this project.

MECHANICAL TESTING

Much of the work done by the section is of a service nature to other sections within PMRL or to industry. New alloys are routinely tested for tensile strength and ductility, as well as for notch toughness. Tests are carried out on request, for example, to determine whether high pressure gas cylinders conform to Canadian Transport Commission specifications. During 1985, a capability was developed to perform CTOD tests on a routine basis at temperatures down to -60°C.

STRESS ANALYSIS

To assist in interpreting mechanical test results (for example, the mechanism by which a defect promotes failure in a pipe, or the fracture toughness of a welded joint) it is essential to be able to calculate and measure the stress pattern in a specimen.

A computer program to solve two-dimensional stress analysis problems is already in place at PMRL. For three-dimensional linear elastic problems, a method based on superposition and collocation has been developed and reported.

Work has now been completed on a refinement of the hole drilling method to study stress gradients at the surface of a sample. The result is a program package which provides the coefficients required to calculate stresses from surface strain relaxations. A unique feature of the package is that the coefficients are corrected for finite thickness.

A study of the distribution of residual stresses near single-pass and multi-pass welds is under way experimentally at PMRL. Complementary theoretical studies (by finite element method calculations) are being carried out under contract at the University of Waterloo. The results will be useful in understanding phenomena such as the initiation of fatigue cracks at weld toes.

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(underlined authors are in the Engineering Physics Section)

Faucher, B.
"Mesure des valeurs élevées de J_{Ic} à l'aide de petites éprouvettes en flexion trois points"; Can Metall Quart; 24:447; 1984.

Fegredo, D.M., Faucher, B. and Snehata, M.T.
"Influence of inclusion content, texture and microstructure on the toughness anisotropy of low carbon steels"; Proc ICSMA7; Eds. H.J. McQueen, J.-P. Bailon, J.I. Dickson, J.J. Jones and M.G. Akben; Pergamon Press; Aug. 12-16, 1985; Montreal; 1127, 1985.

Tyson, W.R. and Marandet, B.
"Experience with the key-curve method for evaluation of crack growth and J-integral during ductile tearing"; Proc ICSMA7 (7th Int Conf on Strength of Metals and Alloys); 1199-1204; 1985.

Vosikovsky, O., Bell, R., Burns, D.J., and Mohaupt, U.H.
"Fracture mechanics assessment of fatigue life of welded plate T-joints, including thickness effect" Behaviour of Offshore Structures - Boss 85; Ed. J.A. Battjes; Elsevier Science Publishers, July 1-5, 1985; Delft, The Netherlands; 453-464; 1985.

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MRP/PMRL 84-80(OP,J) Tyson, W.R. and Marandet, B. "Experience with the key curve method for evaluation of crack and J integral during ductile tearing".

PMRL 85-29(OP-J) Tyson, W.R., and Marandet, A. "Cleavage toughness variability and inclusion size distribution of a weld metal".

PMRL 85-29(OP,J) Faucher, B., and Tyson, W.R. "Factors affecting the fracture toughness of an arctic grade steel".

PMRL 85-38(OP) Vosikovsky, O., Mohaupt, U.H. and Burns, D.J. "Corrosion fatigue in welded steel offshore-structure".

PMRL 85-60(OP) Tyson, W.R. "Material property requirements for steels fixed offshores structures".

Four cost recovery reports were completed by the Engineering Physics Section in FY 85/86.

PRESENTATIONS

(presenting author underlined)

Faucher, B. and Tyson, W.R.
"Measurements of J-resistance curves with three-point-bend specimens"; Int. Conf on Fatigue, Corrosion Cracking, Fracture Mechanics and Failure-Analysis; Salt Lake City, UT; Dec. 1985.

Fegredo, D.H., Faucher, B. and Shehata, M.T.
"Influence of inclusion content texture and microstructure on the toughness anisotropy of low carbon steels"; ICSMA 7; Montreal Aug. 1985.

Tyson, W.R.
"Research on fracture toughness and fatigue at PMRL, CANMET; Cdn Forces/CRAD meeting on Research in Fabrication and Inspection of Submarine Pressure Hulls; DREA, Halifax; May 1985.

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"Cleavage toughness variability and inclusion size distribution of a weld metal; 18th Nat Symp on Fracture Mechanics (ASTM); Boulder, CO; June 1985.

Faucher, B. and Tyson, W.R.
"Factors affecting the fracture toughness of an Arctic grade steel plate"; 18th Nat Symp on Fracture Mechanics (ASTM); Boulder, CO; June 1985.

Tyson, W.R. and Marandet, B.
"Experience with the key-curve method for evaluation of crack growth and J-integral during ductile tearing"; ICSMA 7; Montreal; Aug. 1985.

Tyson, W.R.
"Material property requirements for steel fixed offshore structures"; Seminar on New and Improved Materials for Cold Ocean Applications; TUNS, Halifax; Dec. 1985.

Tyson, W.R.
"Steel selection for cold Arctic applications"; IGM, Montreal; Feb. 1986.

Tyson, W.R. and Faucher, B.
"Reversible temper embrittlement: Current thoughts on thermodynamics, kinetics and mechanics"; Int. Seminar on Solute-Defect Interaction; Kingston, Ont.; Aug. 1985.

Vosikovsky, O., Bell, R., Burns, D.J. and Mohaupt, U.H.
"Fracture mechanics assessment of fatigue life of welded plate T-joints, including thickness effect" Behaviour of Offshore Structures - Boss 85 Delft, The Netherlands; July 3, 1985.

Vosikovsky, O.
"Fracture mechanics prediction of crack propagation life of welded joints"; CCIIW Working Group Meeting; WIC, Oakville, Ont.; May 9, 1985.

Vosikovsky, O., Mohaupt, U.H. and Burns, D.J.
"Corrosion fatigue in welded steel offshore structures"; Conf of Metallurgists, CIM; Vancouver, B.C.; Aug. 20, 1985.

Vosikovsky, O.
"Cathodic protection and fatigue of steels for offshore structures"; NACE Conf., Montreal, Que.; Nov. 13, 1985.

Vosikovsky, O.
"Corrosion fatigue of welded joints for offshore structures"; Invited lecture series. 25th anniversary of Dept of Mech Eng, University of Alberta; Edmonton, Alta.; Jan. 27, 1986.

GRANT AND MONITORING ACTIVITIES

DESIGNATED SCIENTIFIC AUTHORITIES AND LIAISON OFFICERS

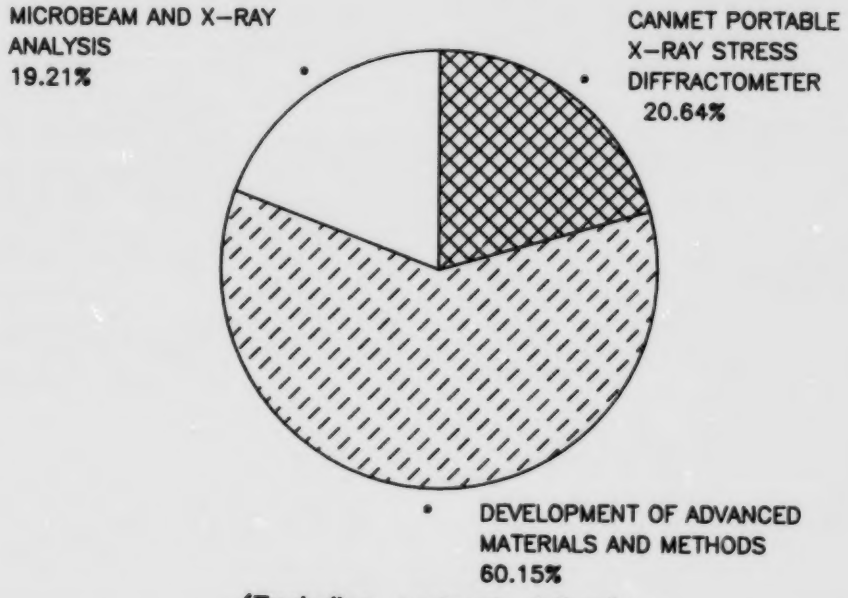
SA/LO	Performer	Project
W.R. Tyson	Det norske Veritas (Canada), Calgary	Evaluation of fracture toughness data with respect to reliability of Subarctic and Arctic offshore structures
W.R. Tyson	Prof. J. Provan, McGill (with Dominion Engineering Works)	The reliability assessment of large cast steel castings
G. Roy	University of Waterloo, Ontario	Finite element modelling of residual stress state in weldments
G. Roy	NRC-IRAP, Ottawa, Ontario	Distortion in panel welds, its numerical modelling and model verification

SA/LO	Performer	Project
G. Roy	Lloyd's Register of Shipping, London, UK	Stress concentration factors for tubular complex joints
G. Roy	Carleton University, Ottawa, Ontario	Investigation of crack propagation of weld toe cracks
B. Faucher	WIC	Wide plate test facility
O. Vosikovsky	AMCA Int/University of Waterloo	Fabrication and evaluation of welded joints in marine environments
O. Vosikovsky	AMCA Int/University of Waterloo/Memorial University of Newfoundland	Fabrication and fatigue evaluation of welded tubular joints in marine environments
O. Vosikovsky	Carleton University	Determination of stress intensity factors for weld toe defects - Phase II
O. Vosikovsky	The Welding Institute	Fatigue performance of repaired tubular joints

METAL PHYSICS SECTION

SECTION HEAD **W.N. ROBERTS** **993-7120**

DEVELOPMENT AND APPLICATION OF ADVANCED INSTRUMENTATION
(EXPRESSED AS PERCENTAGE DOLLAR EXPENDITURE)


MICROBEAM AND X-RAY ANALYSIS 19.21%
CANMET PORTABLE X-RAY STRESS DIFFRACTOMETER 20.64%
DEVELOPMENT OF ADVANCED MATERIALS AND METHODS 60.15%

(Excluding contract dollars)

Project	Lead Scientist	
CANMET PORTABLE X-RAY STRESS DIFFRACTOMETER	R.A. HOLT	993-7085
DEVELOPMENT OF ADVANCED MATERIALS AND METHODS	W.N. ROBERTS	993-7120
MICROBEAM AND X-RAY ANALYSIS	W.N. ROBERTS	993-7120

The primary objective of the Metal Physics Section is to provide support with current X-ray and electron beam analytical services to PMRL's materials research. The section has expertise in X-ray diffraction, analytical electron microscopy, microprobe analysis and scanning electron microscopy. In the current FY it will add ion microscopy to its capability for characterizing the structure and chemistry of materials.

X-RAY DIFFRACTION

The X-ray Diffraction Laboratory has made significant progress in commercializing the CANMET portable X-ray stress diffractometer.

A small company near Windsor, Ont. has constructed the first commercial prototype of the instrument with continued technical support from PMRL, and partial funding from the National Research Council's "Program for Industry/Laboratory Projects (PILP)".

Under test, the mechanical, electronic and computer control systems meet design specifications. Ontario Hydro Research, in an independent evaluation, has found overall performance of the diffractometer satisfactory in laboratory tests. The instrument is scheduled for field trials.

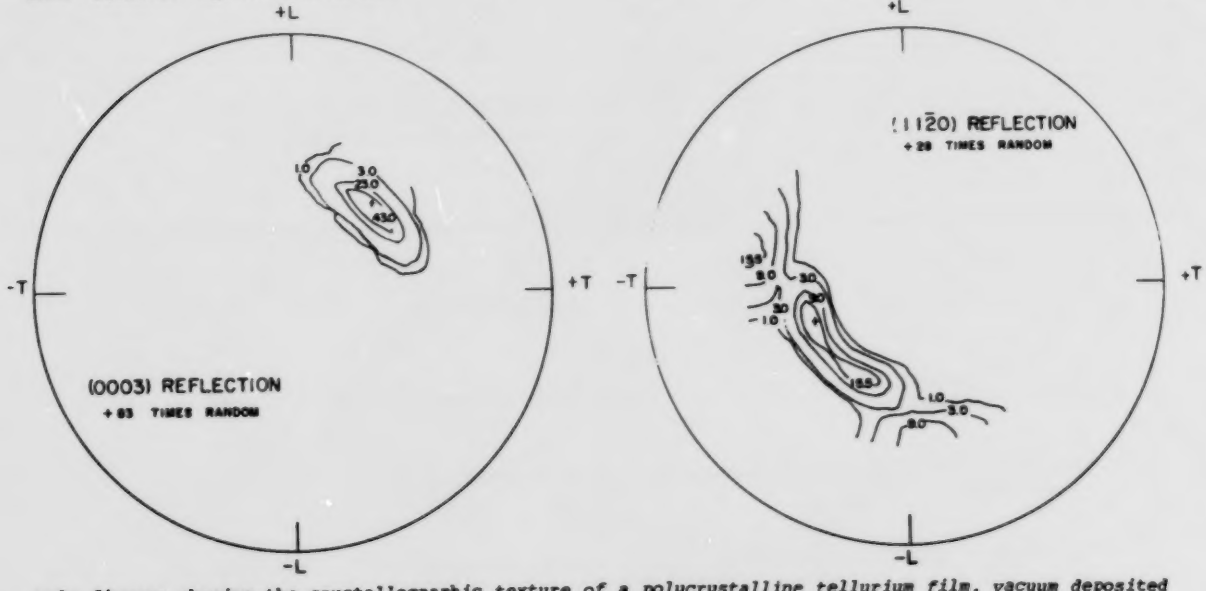
U.S. and Canadian patents on the data acquisition and processing technology of the diffractometer have been granted. Earlier plans to develop a miniature X-ray tube were abandoned when no Canadian manufacturer with sufficient expertise could be found; instead, efforts have turned to having a Canadian company develop a lighter and more flexible high-voltage cable.

A contract with a small Calgary company, to develop a position sensitive X-ray detector based on commercially available solid-state-array imaging devices, was unsuccessful, because they lacked sufficient sensitivity to diffracted X-rays. A special device optimized for X-ray sensitivity might hold more promise but does not seem to be available commercially.

In other work, the diffraction laboratory has programmed a PDP 11/23 computer to control a single crystal diffractometer to determine up to three pole figures simultaneously with a position-sensitive proportional counter. The technique is being used to assess the crystallographic texture of polycrystalline tellurium, to support work at McGill University in developing a device sensitive to infrared laser radiation.

PMRL and Chalk River Nuclear Laboratories have developed a model to predict intergranular stresses in polycrystalline metals from the elastic and plastic anisotropy of single crystals. Qualitatively, the model predicts dimensional changes in zirconium alloys exposed to reactor irradiation, for which there was no previous satisfactory explanation.

Neutron diffraction is an attractive technique for determining strains in materials, because a through-thickness profile of strains can be determined with appropriate collimation of the neutron beam. The diffraction laboratory collaborated with Chalk River Nuclear Laboratories to measure strains in a single-pass weld in 316 L stainless steel, which had been previously measured by X-ray diffraction and strain-gauge methods at PMRL and analyzed by finite element techniques at the



Pole figures showing the crystallographic texture of a polycrystalline tellurium film, vacuum deposited on a single crystal silicon substrate. The pronounced crystallographic texture - apparently due to alignment of the [0003] direction of tellurium with one of the [110] directions of the substrate gives the film anisotropic electro/optical properties with potential for application in laser technology.

University of Waterloo. The measured strain distribution does not coincide with the distribution predicted by the model. Thus, further refinements of the model and experimental techniques are called for.

ANALYTICAL ELECTRON MICROSCOPY

Microstructures in a wide variety of materials have been determined with the Philips EM400T analytical electron microscope (TEM/STEM). Ion beam thinning has been used extensively to prepare specimens from materials such as minerals, semiconductors and certain alloys (e.g., cast alloys) that cannot be thinned by electropolishing.

X-ray analysis, convergent beam microdiffraction and electron energy loss spectrometry are now used routinely to identify finely disposed phases.

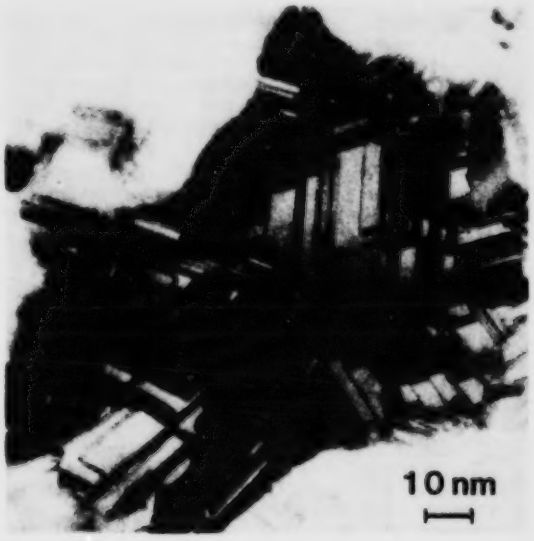
The microscope has been operated almost continuously with an LaB_6 cathode as the electron source. This cathode gives a high beam intensity and has a long-term stability which reduces contamination in the high vacuum system.

Many electronic materials have been examined in collaboration with industry and the National Research Council, including plan view and cross-section specimens of polycrystalline silicon films and, GaAs-based devices, as well as epitaxial layers and thin films deposited by laser evaporation.

A detailed study has been made of polycrystalline silicon films, formed by low pressure chemical vapour deposition. Such films are an essential component of many VLSI devices. Earlier X-ray studies had been interpreted as indicating silicon (normally cubic) with a hexagonal crystal structure. Detailed experiments with convergent beam microdiffraction and high resolution imaging have shown that the only phase present is normal cubic silicon. Large densities of crystal defects in the form of microtwins are responsible for the extra reflections in the X-ray patterns.

The last decade has seen an extremely rapid increase in research on metallic glasses, partly because of the development of the melt spinning process (see under "Metallurgy Section" for details). Because of the extremely fine-scale microstructures often encountered in these materials, analytical electron microscopy is a particularly suitable technique for studying materials produced by ultra-rapid solidification.

To gain experience, ribbons of NiZr alloys produced at McGill University have been studied. Difficulties in preparing specimens caused by their small dimensions, were overcome by ion-beam thinning. In some cases, complex microstructures containing small (~10 nm diameter) crystals of Ni_5Zr have been observed. An important result of this study was the identification of a metastable b.c.c. form of nickel (normally f.c.c.) in the form of large crystals (~0.5 μm diameter) which occured in strip produced at slower cooling rates.



Transmission electron micrograph of a single grain in polycrystalline, cubic silicon formed by low pressure chemical vapour deposition for microelectronics applications. The microtwins shown, which are as thin as 1-2 atom layers, are believed to be the cause of anomalous X-ray diffraction peaks that had been ascribed in the literature to a hexagonal modification of silicon. Mag. x 700,000

The TEM/STEM has been used in many other diverse studies, of which the following are typical:

- welds in microalloyed steels; the distribution of carbonitride precipitates has been studied as a function of distance from the fusion line
- ferritic stainless steels; the precipitation of carbonitrides of Nb has been examined as a function of heat treatment in work to assist in developing improved industrial processing procedures
- bronze propeller alloys; work has continued on the analysis of phase structure and precipitates to further the understanding of the solidification process
- rail steels; microstructures have been examined to help develop the industrial practices necessary for optimizing the mechanical properties of premium rails
- Al-Li alloys; the phases present in lightweight alloys of Al-Li have been characterized following processing (see under "Metallurgy Section" for further details).

SCANNING ELECTRON MICROSCOPY

The scanning electron microscope has been used extensively in conjunction with an energy dispersion X-ray spectrometer. As a result, it is

now possible to obtain quantitative chemical analyses of regions when they are micrographed. The following are examples of investigations to which this instrument has been applied:

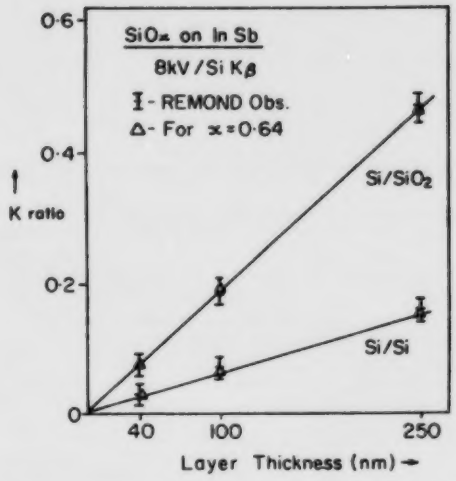
- defects in collector coinage for the Royal Canadian Mint
- heat-affected zones in weldments of titanium-modified microalloyed steels and heat-affected zones simulated in the Gleeble apparatus
- microalloyed steels for linepipe
- rapidly-solidified alloys prepared by melt spinning
- steels for premium rail.

ELECTRON MICROPROBE

Research on electron microprobe analysis has concentrated on further improving the accuracy of measurements and extending the range of applications of the instrument. Papers and presentations have been given on the quantitative electron probe microanalysis of small particles and films, on quantification of the surface analyses, on the analyses of catalysts and hydrocracker reactor products, on analyses of surface films on polished sulphide minerals, and on the surface analysis of corrosion inhibitors. A general equation has been written for predicting X-ray intensities from stratified samples. In recognition of this body of original work, the scientist in charge was chosen Tour Speaker of the Microbeam Analysis Society for the Spring of 1986, the first time a Canadian has been given this particular honour.

The electron microprobe has been applied to a number of industrial problems. The following are examples of studies which have been undertaken with this instrument:

- segregation in steels for two Canadian steel companies
- elemental distributions in optical fibres for a large Canadian manufacturer of optical communication systems
- composition of multilayer semiconductor materials for local microelectronics companies and the National Research Council



Silicon monoxide (SiOx), used extensively in the microelectronics industry, is known to be a mixture of SiO_2 and Si (metal). However, the exact ratio is poorly known. The experimental data, from Dr. Guy Remond of the Bureau de Recherches Géologiques et Minières, Orleans, France, show intensity ratios for SiK_β radiation from SiOx layers of three different thicknesses, generated by 8 kV beam of incident electrons. The intensity rated "K" is the number of corrected counts from a thin layer of thickness "y" divided by the counts from a solid sample of the same material. There is a chemical shift in the k_β radiation which permits separate determinations of intensities from the SiO_2 and the Si in the mixture. When approximately 0.61 Si is assumed in the silicon monoxide, predicted intensity ratios lie on the same lines as experimental values. The predictions are based on the new "layered specimen" theory developed at PMRL; heretofore, data from layered specimens could not be treated accurately by conventional microprobe correction programs.

- identification of corrosion products from test coupons exposed in the experimental fluidized bed combustor at Point Tupper, N.S.
- identification of impurities in copper anodes for a Canadian mining company.

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Hutchison, T.S., Ocampo, G. and Carpenter, G.J.C.
"Crystal structure and morphology in commercial NbTi (46.5 wt % Ti) superconducting fibres; Scripta Met; 19:635; 1985.

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"The morphology of LPCVD polycrystalline Si"; Microscopy of semi-conducting materials 1985; Eds. A.G. Cullis and D.B. Holt, March 25-27, 1985; Oxford, England; Inst of Physics; 145, 1985.

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"Surface quantification in the electron microprobe"; Microbeam Analysis - 1985; Ed. J.T. Armstrong, Aug. 5-9, 1985; Louisville, KY; San Francisco Press; 97, 1985.

Remond, G., Kosakevich, A., Ruzakowski, P., Packwood, R. and Taylor, J.
"X-ray spectrometry, electron spectroscopies and optical micro-reflectometry applied to the study of ZnS tarnishing in polished ore specimens"; SEM - 1985; Ed. O. Johari; Chicago, IL; 1985.

Vandervorst, W., Houghton, D.C., Shepherd, F.R., Swanson, M., Plattner, H. and Carpenter, G.J.C.
"Residual damage in B and BF_2 implanted Si"; Can J of Physics; 63:863; 1985.

Woo, O.T. and Carpenter, G.J.C.
"γ-TiH: an isomorph of γ-ZrH"; Scripta Met; 19:931; 1985.

AVAILABLE PMRL REPORTS

PMRL 85-58(INT) Roberts, W.M. and Packwood, R.H.; "Applications of ion microscopy/secondary ion mass spectrometry to research in PMRL/CANMET."

MRP/PMRL 85-6(OP-J) Sastri, V.S., Packwood, R.H., Moore, V.E. and Bednar, J.; "Surface analysis in studying corrosion inhibition mechanisms."

MRP/PMRL 85-10(OP-J) Packwood, R., Sastri, V.S. and Brown, J.D.; "Surface quantification in the electron microprobre."

MRP/PMRL 84-73(J) Mainville, J., Crawley, A.F., Cousineau, E. and l'Esperance, G.; "Influence of crystallographic texture during forming on dual-phase steels."

PMRL 85-25(TR) Packwood, R.H. and Milliken, K.S.; "A general equation for predicting X-ray intensities from layered samples in the electron microprobe."

Two cost recovery reports were completed by the Metal Physics Section in FY 85/86.

PRESENTATIONS

(Presenting author underlined)

Bowker, J.T., Malis, T. and Ng-Yelim, J.
"Characterization of precipitates in the weld heat-affected zone for a range of offshore steels"; Metal Physics Conf; Kingston, Ont., June 6, 1985.

Carpenter, G.J.C.
"Applications of analytical electron microscopy to materials research" (invited talk); Department of Physics, McGill University; Montreal, April 24, 1985.

Carpenter, G.J.C., Cherns, D. and Mallard, R.
"The origin of anomalous diffraction peaks in polycrystalline silicon films"; Fall Meeting of the Materials Research Society; Boston, MA, Dec. 2-7, 1985.

Carpenter, G.J.C., Mallard, R. and Houghton, D.C.
"Some applications of electron microscopy to studies of semi-conducting materials"; Can Metal Physics Conf; Royal Military College, Kingston; June 5-7, 1985.

Gilbert, R.W., Griffiths, M. and Carpenter, G.J.C. (poster)
"Solute depletion and phase instability of intermetallic particles in zirconium alloys"; Can Metal Physics Conf; Royal Military College, Kingston; June 5-7, 1985.

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Packwood, R.
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"Ion implantation in CdAs"; Intnl Conf on Radiation Effects in Insulators - III; University of Surrey, England, July 15-19, 1985.

Ternan, M. and Packwood, R.
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"Effect of stress relaxation on the recovery and recrystallization of copper; mechanical, optical and electron microscope determinations"; Can Metal Physics Conf; Royal Military College, Kingston; June 5-7, 1985.

Woo, O.T. and Carpenter, G.J.C.
"γ-TiH: an isomorph of γ-ZrH"; AIME Fall Meeting; Toronto, Ont., Oct. 14-17, 1985.

Zee, R.H., Carpenter, G.J.C. and Rogerson, A.
"Irradiation growth in deformed zirconium"; AIME Fall Meeting; Toronto, Ont., Oct. 14-17, 1985.

GRANT AND MONITORING ACTIVITIES

DESIGNATED SCIENTIFIC AUTHORITIES AND LIAISON OFFICERS

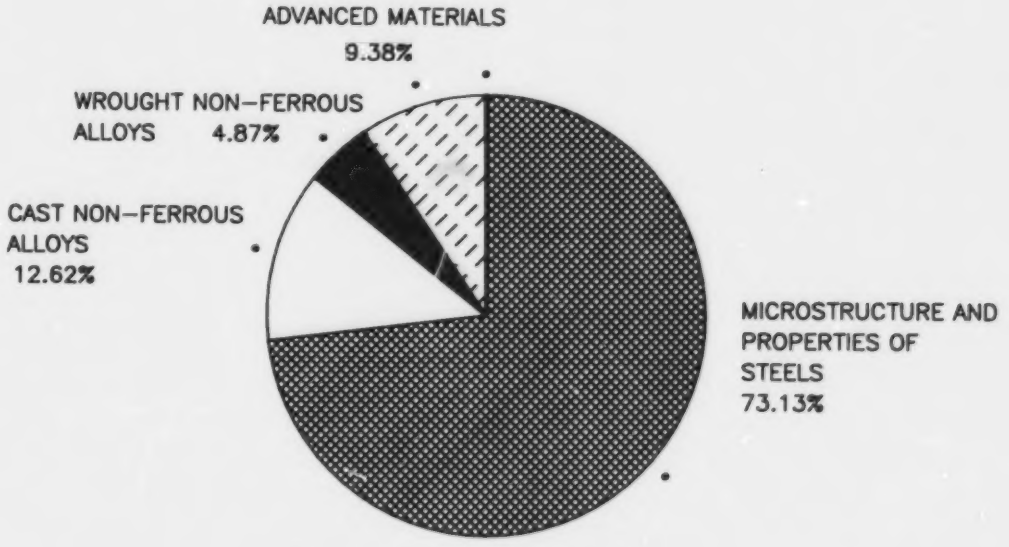
SA/LO	Performer	Project
G.J.C. Carpenter	Dr. M.A. Clark, Dept. of Metallurgy, Ontario Hydro Res.	In-situ metallographic examination of ferrous and non-ferrous components
G.J.C. Carpenter	Prof. G.R. Piercy, Dept. of Metallurgy, Queens University	Microstructure of compound semiconductor devices
G.J.C. Carpenter	Prof. S. Saimoto, Dept. of Metallurgy, Queens University	A direct determination of preferred grain boundary precipitation in stainless steels to facilitate design of thermo-mechanical processing
R.A. Holt	Chalk River Nuclear Labs	Neutron diffraction measurements of residual stress in a stainless steel weldment
R.A. Holt	Itres Research	Design and construct a prototype position sensitive X-ray detector
R.A. Holt	Proto Mfg Ltd.	Development of compact head, computer interface system, and field package for engineering model of CANMET portable stress diffractometer

SA/LO	Performer	Project
R.A. Holt/ D.W.G. White	Proto Mfg Ltd.	PILP contribution arrangement for CANMET protable stress diffractometer
R. Packwood	J.D. Brown U.W.O.	Co-operative Research & Development Grant CRD-8441 - HSLA steel smut problem at Algoma Steel.

METALLURGY SECTION

SECTION HEAD J.D. BOYD 993-7129

MICROSTRUCTURE AND PROPERTIES OF ENGINEERING ALLOYS
(EXPRESSED AS PERCENTAGE DOLLAR EXPENDITURE)



(Excluding contract dollars)

Project	Lead Scientist	
MICROSTRUCTURE AND PROPERTIES OF STEELS	J.D. BOYD	993-7129
CAST NON-FERROUS ALLOYS	J.D. BOYD	993-7129
WROUGHT NON-FERROUS ALLOYS	J.D. BOYD	993-7129
ADVANCED MATERIALS	L.E. COLLINS	993-7129

Research activities in this section are concerned with the microstructure-sensitive properties of engineering materials, the control of microstructure by composition and processing, and characterization of microstructure. The ultimate objective in each project is to develop predictive models of the microstructure-property relations, which can be used to design improved materials. State-of-the-art metallographic and analytical techniques are employed to characterize microstructures, and work is done on developing new techniques for automatic image analysis and electron energy loss spectroscopy (EELS).

Research projects on steels are primarily concerned with the effects of microalloying as well as of inclusions and residual elements. This work comprises such steel products as line-pipe skelp, structural plate, rail, machinery steels and spring steels. Research on non-ferrous alloys includes cast Cu-base alloys and wrought Al alloys. Work is expanding on investigations of the remarkable microstructures and properties of rapidly solidified materials. Major projects in this field of research include studies of the corrosion behaviour of melt-spun Cu alloys and stainless steels, and the magnetic properties of amorphous Fe-base alloys.

MICROSTRUCTURAL CHARACTERIZATION

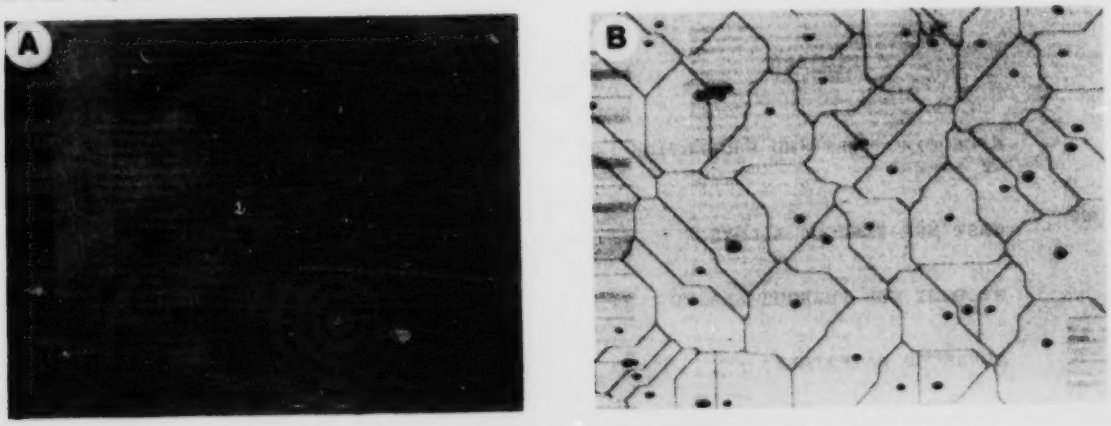
Procedures have been developed for characterizing particle-spacing distributions using automatic image analysis and a micro-computer. Distributions are characterized by the distribution of local volume fraction of particles based on either a cell construction produced directly by the image analyzer ("octagonal dilation method"), or by a Dirichlet tesselation computed from particle coordinates. The degree of "randomness" or "clustering" of a dispersion of particles is determined by comparing the measured distribution of the local volume fraction with computer-generated distributions. Progress was also made in detecting features for image analysis based on their chemical composition.

In collaboration with scientists in Canada, the U.S. and the U.K., quantification factors for electron energy loss spectroscopy (EELS) were determined for the microanalysis of light elements in metals, alloys and ceramic materials.

MICROALLOYED STEELS

The effects of alloying, deformation and cooling rate on austenite transformation behaviour and microstructure development in steels has been studied using a quench-deformation dilatometer. Simulations of accelerated cooling have been carried out on a number of microalloyed steels including a Ti-V steel, a Mo-Nb-V-Ti steel and a series of ultra low carbon bainitic steels containing boron. The transformation temperatures and microstructures obtained in the dilatometer simulations correlate well with those obtained in laboratory plate rolling trials. As more steels are tested, a database is being accumulated from which it will eventually be possible to develop models to predict transformation behaviour. A number of cost-recovery projects were undertaken with the dilatometer. These included simulation of a wire annealing process (Stelco), determination of continuous-cooling-transformation (CCT) diagrams for two high strength low-alloy steels (Ipsco), and a study of the effects of deformation on the transformation behaviour of a sheet steel (Dofasco).

The microstructures of many of the microalloyed steels whose transformations were characterized by dilatometry were also studied by transmission electron microscopy (TEM) and analytical electron microscopy (AEM). Progress was made in correlating the images of microstructural constituents in the steels which are observed by SEM and TEM. This was greatly aided by the development of a method for rapidly mapping the thickness of any location in a thin foil specimen using EELS. This technique was used to identify of a new transformation product which strongly influences fracture properties of microalloyed steels.



Octagonal dilation of inclusions in (A) by the image analyser to produce cell structure with boundaries at mid-distance between adjacent inclusions (B).

The through-thickness fracture properties were determined for 25-mm thick plate of a Ti-V micro-alloyed steel processed by different thermomechanical schedules. Specific microstructural sources of brittleness and reduced ductility were identified. The effect of test temperature on the critical stress or strain for fracture of a given steel was represented by an experimentally-determined fracture map.

The work on ultra low carbon bainitic (ULCB) steels (contract-Laval U.) indicates that property requirements can be met at 0.04 ppm C and 60 ppm N, which should be achievable in commercial steelmaking. Accelerated cooling is necessary to obtain a fully bainitic structure and optimum properties. The effectiveness of B is dependent on the processing schedule. Dilatometer studies are in progress to delineate the relationship between processing and B hardenability.

OTHER STEELS

The effects of inclusions and microstructure on the gauge-face, adhesive wear of rail steels was investigated using the National Research Council (NRC) laboratory rail-wheel simulator. Manganese sulphide inclusions strongly promote this type of wear, whereas oxide inclusions have little effect. Wear resistance generally increases with increasing hardness though bainitic microstructures are more susceptible to crack formation and propagation than pearlite of similar hardness.

A computational method was developed to determine the post-rolling cooling conditions to produce specified hydrogen concentrations in rail. In other work, the effect of cooling condition on the microstructures of flash-butt welds has been determined by dilatometer and Gleeble simulation.

Both the mechanics and the metallurgy of machinability in medium carbon steels were studied (contract-McMaster U.). A slip-line field model has been developed to calculate stresses and strains in the primary deformation zone. Experimental studies of chip formation show that the critical accumulated damage for fracture is a function of machining speed. At low speeds, chip formation is controlled by the type and distribution of inclusions, whereas at high machining speeds the flow stress and strain-hardening rate are important. A thermodynamic database is being developed for steelmaking processes involving Ca treatment to ensure the presence of soft inclusion phases which promote long tool life.

The toughness of Cr-Mo and C-Mn weld metals was measured and correlated with quantitative measurements of inclusion distributions. Low-temperature toughness is determined by the largest inclusions. This illustrates the importance of measuring extreme, rather than the average, values of defect size.

NON-FERROUS ALLOYS

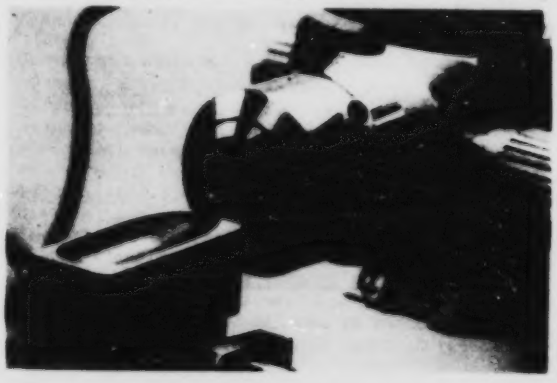
A remedial heat treatment was developed which doubles the impact toughness of Mn-Ni-Al bronze propeller castings without sacrifice in strength. Beta phase was identified as the brittle phase in these alloys, and it was found that the remedial heat treatment precipitates a dispersed phase which promotes ductile fracture within the beta phase. A comprehensive study was begun of the fracture toughness and the fatigue/corrosion fatigue crack propagation behaviour of Mn-Ni-Al bronze alloys containing 8-14% Mn (contract-Ecole Polytechnique).

In collaboration with Alcan, the distribution of Li in experimental and commercial Al-Li alloys was determined by quantitative EELS. A specimen preparation technique that employs ultra-microtomy was developed for this project that is now used for preparing TEM and EELS specimens of various metallic and non-metallic materials.

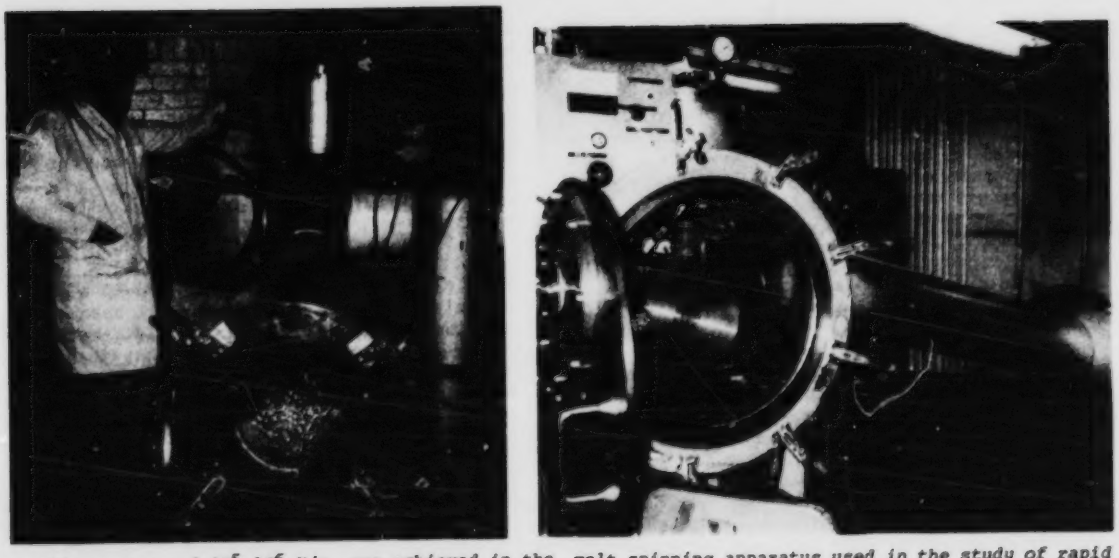
RAPIDLY SOLIDIFIED MATERIALS

The corrosion resistance of melt-spun Fe-Al bronze containing up to 7% Fe was shown to be far superior to that of conventional sand-cast material. The improvement is attributed to the microstructural refinement and chemical homogeneity of the melt-spun material. A small improvement in the resistance to general corrosion and intergranular corrosion was demonstrated for melt spun stainless steel grades 304, 316 and 410, and a melt spun low-Cr (14%) alloy had similar corrosion properties to conventional grade 304 stainless steel (contract - Sinteris Canada). In a study of the corrosion fatigue behaviour of magnetic metallic glasses, Fe-Ni-base alloys performed better in salt water and H_2SO_4 environments than Fe-base alloys (contract-Manitoba Research Council).

The efficacy of explosive compaction to consolidate powders was evaluated. Fe, Cu and brass powders were consolidated to 90% theoretical density in a series of tests in which the effects of type and quantity of explosive, and compaction configuration on the bonding of compacts were investigated (contract - Limpact Industries). A study of roll compaction of melt-extracted Ni fibres



Diamond knife ultramicrotome used to slice sections of metals, composites and even ceramics for analytical electron microscopy. Sections may be as thin as 50-100 atoms.



Cooling rates of 10^5-10^6 K/s are achieved in the melt spinning apparatus used in the study of rapid solidification.

indicated that the process is feasible, but further development is required to obtain suitable mechanical properties (contract - Sherritt Gordon Mines).

Work commenced on rapidly-solidified Fe-Si-B and Fe-Nd-B alloys for transformer cores and permanent magnets respectively. In addition to investigating the magnetic properties of these materials, work is proceeding on increasing the width and improving the quality of the melt-spun ribbon. In co-operation with the University of Waterloo, the production and properties of metal-matrix composites reinforced with Fe-base metallic glass ribbons are being studied. Amorphous films of Fe-Zr and grade 304 stainless steel containing Zr have been produced by sputtering, and are being characterized.

PAPERS PUBLISHED IN OUTSIDE JOURNALS AND CONFERENCE PROCEEDINGS

(Authors from the Metallurgy Section underlined)

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"The mechanical properties of 2.25 Cr - 1 Mo weld metals deposited by the SAW-NG process"; J of Mats for Energy Systems, ASM; 7:2:137; Sept. 1985.

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MRP/PMRL 84-28(TR) Collins, L.E. and Barry, J. "Operation of the MMC Quench-Deformation dilatometer".

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MRP/PMRL 84-79(TR) Collins, L.E. and White, D.W.G. "Current Canadian activities in rapid solidification technology (RST)".

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MRP/PMRL 85-2(OP-J) Fegredo, D.M., Shehata, M.T., Palmer, A. and Kalousek, J. "The effect of inclusion type and control on the wear of an alloy rail steel".

MRP/PMRL 85-8(OP-J) Fegredo, D.M. and Connors, E. "Modified in-line and accelerated normalizing to improve properties and conserve time and energy".

ERP/PMRL 85-18(INT) Knight, R.F. "Structure and properties of line-pipe steel given a simulated OLAC treatment".

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PMRL 85-35(OP-J) Shehata, M.T., Chandel, R., Braid, J.E.M. and McGrath, J.T. "Characterization of non-metallic inclusions in weld metals".

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Bowker, J.T., Malis, T. and Ng-Yelim, J. "Characterization of precipitates in the weld heat affected zone for a range of offshore steels"; Metal Physics Conference; Kingston, Ont.; June 5-7, 1985.

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"Short-range order in amorphous alloys"; Séminaire de physique des solides; Universite de Montréal, April 1985.

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"Mossbauer spectroscopy in microelectronics"; Seminar Thin Films Group; École Polytechnique de Montréal, Aug. 1985.

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GRANT AND MONITORING ACTIVITIES

DESIGNATED SCIENTIFIC AUTHORITIES AND LIAISON OFFICERS

SA/LO	Performer	Project
J.D. Boyd	D.A.R. Kay, McMaster University	Metallurgical aspects of machinability in medium carbon steels
J.D. Boyd	I. Dickson, École Polytechnique	Study of fracture toughness and corrosion-fatigue of bronze propeller alloys
J.D. Boyd	R. Smith, Queens University	A study of the dissolution of elements in liquid aluminum
L.E. Collins	Sherritt Gordon Mines Ltd.	Compacting characteristics of rapidly solidified particulates
L.E. Collins	Sinteris Canada Inc.	The development of rapidly solidified stainless steel alloys for P/M applications
L.E. Collins	Manitoba Research Council	An investigation of the corrosion fatigue behaviour of magnetic metallic glasses
L.E. Collins	Limpact Industries Limited	High energy rate compaction of rapidily solidified metal powders
L.E. Collins	Laval University	Ultra to low carbon boron HSLA steels: Influence of alloying and processing on the transformation kinetics and mechanical properties
L.E. Collins	Battelle	Laser surface modifications for fatigue and wear control
T. Malis	Dr. J.D. Embury McMaster Univ.	Control of recrystallization in Al alloys
M. Sahoo	Queen's Univ.	Structure and mechanical properties of directionally solidified zinc-aluminum foundry alloys
M. Sahoo	McGill Univ.	The optimization and control of the modification of Al-Si alloys by strontium
M. Sahoo	Queen's Univ.	The design and production of high quality nonferrous castings

RESEARCH CONTRACT REPORTS

(In order of completion)

705402 Sahoo, M. "Structure and mechanical properties of directionally solidified Zn-Al foundry alloys". Final report. Prepared by R.W. Smith, Queens Univ.

425254 Boyd, J.D. "Determination of the ability of Stelco ingot and strand cast structural plate to meet the mechanical property requirements for Canadian offshore structures and ships". Prepared by Stelco Inc.

425101 Boyd, J.D. and Malis, T. "Scanning transmission electron microscopy of microalloyed steels". Prepared by J.D. Embury and G.C. Weatherly.

420603 Godden, M.J. "The effect of niobium on the heat-affected-zone toughness of Arctic grade linepipe (IP-S-457)". Prepared by Stelco Inc.

420603 Godden, M.J. "Evaluation of replication methods for the study of HAZ structures in multipass weldments and the preparation of EELS standards". Prepared by Stelco Inc.

360251 Parsons, D.E. "Development of non-leaded free machining steels Phase IV". Final report April 1984 to March 31, 1985. Prepared by S.V. Subramanian and D.A.R. Kay.

420251 Sahoo, M. "Corrosion-fatigue of Mn-Ni-Al bronze propeller alloys". Final report. Prepared by École Polytechnique.

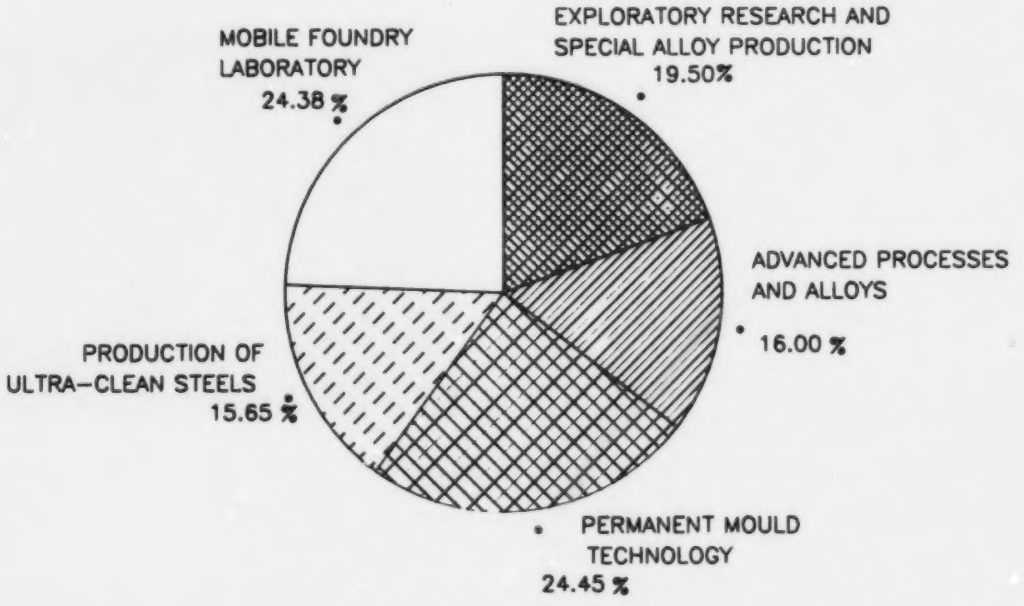
METALS PROCESSING LABORATORY

MANAGER	R.THOMSON	993-7075

FOUNDRY SECTION

SECTION HEAD **R.K. BUHR** **993-7148**

DEVELOPMENT OF CASTING PROCESSES
(EXPRESSED AS PERCENTAGE DOLLAR EXPENDITURE)



(Excluding contract dollars)

Project	Lead Scientist	
EXPLORATORY RESEARCH AND SPECIAL ALLOY PRODUCTION	R.K. BUHR	993-7148
ADVANCED PROCESSES AND ALLOYS	R.K. BUHR	993-7148
PERMANENT MOULD TECHNOLOGY	K.G. DAVIS	993-7148
PRODUCTION OF ULTRA-CLEAN STEELS	A.R. PALMER	993-7076
MOBILE FOUNDRY LABORATORY	R.K. BUHR	993-7148

DEGRADABLE FOUNDRY SAND BINDERS:

Efforts to shorten the curing time of citric/gluconic acids-limestone and citric/malic acids-limestone bonded moulds continued. Modification of acid concentrations, pre-heating the sand, etc., all had some effect, but these measures also shortened the working life of the moulding mix. The innibiting effect of residual CO_2 on the reaction between limestone and the acids in the syrup was noted and subsequently was confirmed by comparing the solubility of calcium citrate in "plain" and in CO_2-saturated distilled water. Based on these findings the use of vacuum and purging with air were both found to shorten the curing time of moulds. The beneficial effect of the vacuum treatment was demonstrated to personnel from the foundry industry.

Concurrently, techniques have also been investigated in which glyoxal could be condensed to bond foundry sand. Light magnesia was found to be an effective but slow curing additive, however, by taking up magnesium, zinc, or ferric chloride in the glyoxal solution, prior to the introduction of the condensing additive, the curing time was significantly reduced.

Solutions of sugars and sugar alcohols were also investigated as potential foundry sand binders. These liquids could be caused to reject the dissolved solute by adding calcined lime or dolomite to the mix. The latter substances exhibit great affinity for water, removing it from the sugar solutions. The precipitated solutes in turn bonded the grains of sand into a coherent, monolithic mass, suitable for foundry applications.

All of the methods described have been employed in the preparation of experimental moulds, which were subsequently poured. The temperatures were limited only in one modification, that in which zinc chloride was employed as a cure shortening agent. Moulds bonded in this manner were found to be unsatisfactory for metal poured above 732°C, the volatilization temperature of zinc chloride at atmospheric pressure.

LOW PRESSURE CASTING

Permanent Mould

Casting trials were completed for the zinc-aluminum alloy series Zn-8 Al, Zn-12 Al and Zn-27 Al using both "cup" and "wheel" dies. Defect-free castings were produced in the 27% Al alloy with only a small modification to the die coating procedure to counteract a hot spot in the casting. Acceptable castings in the 12% alloy were produced after extensive experimentation with casting and coating parameters to overcome shrinkage and hot-tearing problems. The severity of these defects in the 8% alloy precluded the production of acceptable castings.

Disposable Mould

Development of this process continued for the production of aluminum and ferrous alloy automotive castings. For aluminum-base automotive castings, the disposable mould process was refined sufficiently that acceptable castings could be produced with both coated and uncoated expanded polystyrene patterns. These refinements included optimization of casting temperatures and pressure differentials, and the use of a suitable sand. Process parameters were also defined for coated patterns, including a casting temperature which was substantially below that used commercially. The production of castings using both coated and uncoated patterns was demonstrated to officials from an automotive company who have revisited CANMET for technical discussion and further evaluation of the process as a candidate for future expansion at the firm's Canadian foundry facilities.

Photograph of a V-6 3 L lower manifold aluminum casting. This was made using the Low Pressure Disposable Mould Casting Process developed at CANMET and using an evaporative foam pattern supplied by Ford of Canada.

A modified ladle system, designed and fabricated in the foundry section, has been used to simulate the characteristics of the low pressure furnace for the production of grey iron castings by the disposable mould process. This ladle system has eliminated the substantial expenditures in plant and personnel which had been budgeted for the development of a high-temperature, low-pressure furnace at CANMET and may lead to the development of low-cost commercial casting technology. Iron castings have been produced successfully by this process and are undergoing metallurgical evaluation before further trials are conducted.

Zinc-Aluminum Foundry Alloys

The effect of strontium, calcium and sodium modification on the corrosion of Zn-27 Al was investigated in a joint project with Cominco Research Labs. The aging of cast-to-shape 1/2 inch test bars for 10 days in air at 95°C had little effect,

whereas 10 days in steam at 95°C showed the following: -

2 levels of Ca modification -

a 4% increase in weight,
a 4% increase in diameter,
considerable cracking, and
a small decrease in tensile stength.

1 level of Na modification -

a 0.2% increase in weight, and
a negligible increase in diameter.

2 levels of Sr modification -

a 1/2% increase in diameter, and
a small decrease in tensile strength.
The appearance was superior to the unmodified Zn-27 Al bars after the same steam corrosion test.

Energy & Cost Analysis of Electric Induction Melting

In this joint project with Ontario Hydro, spreadsheet programs were used to analyze energy consumption figures collected at 15 minute intervals from induction melting furnace power packs and plant transformers during a one month period at 8 Ontario iron foundries. General spreadsheet programs were written as process models with typical information available to the foundryman. Three separate cases were examined: (a) one furnace, one power pack; (b) two furnaces, one power pack; and (c) three furnaces, two power packs. The results have been reported to two foundries and the reports to the other 6 are under consideration.

The furnace operating procedures, the various melting campaign options and melt department costs are considered in an expanded cost program similar to the one used several years ago for cupola melting. The use of the spreadsheet required a new approach to monitoring casting yields and cost of scrap metal returns. The programs have been used to examine the production costs of several iron foundries making three types of iron. A draft of the computer program manual is available. The information has formed a solid basis for energy management in Canadian foundries and considerable savings are expected at the two foundries already analyzed.

GRAVITY PERMANENT MOULD CASTING

The finite difference computer model for solidification in permanent moulds, being written under contract, has now attained a moderate level of sophistication. Water-cooling channels have been included in the treatment, and differentiation is made between top and bottom gating. A stress analysis program using finite elements has also been written. The model is restricted to two-dimensional or axisymmetric geometries.

Further work on inmold ductile cast iron, in which MgFeSi is contained in a reaction chamber located within the cast iron mould, has confirmed that while chill-free iron with desirable microstructures can be produced in this manner, dross is a major problem. Cast inoculant inserts at the chamber outlet are extremely effective in reducing chill, which allows the use of lower carbon-equivalent irons in which dross problems are greatly reduced. Work has started on water-cooled aluminum moulds. The casting being made is a simple 1.2-in diameter rod with a 3/16-in tab at the base. Preliminary results from an unalloyed aluminum mould show virtually no mould wear after approximately 50 castings have been poured. With efficiently inoculated high carbon equivalent irons, the base tab can be made chill-free. Late inoculation with cast inserts located in a core placed above the mould were again found to be very effective. Moulds made from two types of aluminum alloy, each more resistant to physical abuse than the unalloyed aluminum, have been cast and are ready for testing.

Thermal fatigue tests on candidate permanent mould cast irons are continuing. In these tests, the surface of a cylindrical specimen with an axial water-cooling channel is repeatedly heated by induction and then allowed to cool. Grey, ductile, and compacted-graphite test pieces are cycled, in two modes. In one, the surface is heated to a constant 600°C. In the other, the specimen is given a standard power input. Cycle time is approximately 2 min. Observations of cracking at up to 5000 cycles have indicated there is a critical surface temperature between 500 and 600°C below which a very long service life can be expected. The critical temperature does not vary greatly with the type of iron, and so thermal conductivity is the most important factor in determining suitability as a mould material. In the 600°C tests, only pearlitic ductile iron and a pearlitic grade of an alloyed grey iron were crack-free at 1500 cycles. Of the grades tested, the best are a high carbon equivalent "Eaton" grey iron with 3.5°C, 2.5 Si, 0.8 Mn, and a grey iron with lower carbon equivalent popular in Europe as a mould material containing 3.5°C, 1.9 Si, 0.8 Mn, 0.8 Cu.

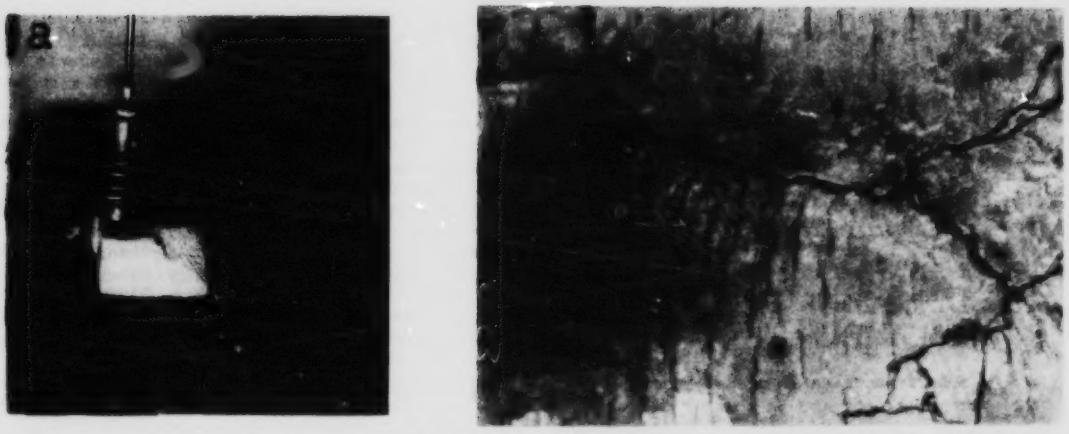
*CANMETcoat Digger Teeth

A number of digger teeth were cast using the CANMETcoat process to produce an abrasion-resistant surface on the digging edges. These were field tested at the Syncrude operation in Fort MacMurray, Alberta. The field testing has shown a significant improvement in service life of the CANMETcoat teeth, and Syncrude has indicated interest in converting to these teeth for their bucket wheel excavators.

Electroslag Casting

Work has been concentrated on the production of nickel-aluminide ingots using electroslag casting (ESC) techniques. Considerable problems have been

*Formerly CANCOAT. CANCOAT can no longer be used as it is already a registered industrial trademark.



Thermal fatigue testing of cast iron mould materials. a) testing rig b) cracks on the surface of an alloy iron after 4500 cycles to approximately 600°C (mag x 10).

encountered with low ductility in the manufacture of parts using nickel-aluminide. Using electroslag casting techniques has resulted in a significantly lower sulphur content and a more closely controlled microstructure such that up to 50% cold work has been achieved at CANMET without cracking. Additionally, replacement of hafnium with zirconium for sulphur control, has also been investigated, with promising results.

This work is being conducted with Oak Ridge National Laboratories (ORNL) in the United States, and billets of the ESC nickel-aluminide have been sent to ORNL for investigation related to their use as permanent mould dies.

Ultra Clean Steels

Work with 20-kg vacuum induction melts has produced steel free of the large particles and oxide clusters which commonly reduce the service life of structures and machine parts. Work is in progress to reduce the quantities of small dispersed particles to "ultra-clean" levels. Similarly, encouraging results have also been obtained from a few 225 kg vacuum induction furnace melts but progress there has been slow because of the operating problems and modifications needed for the system.

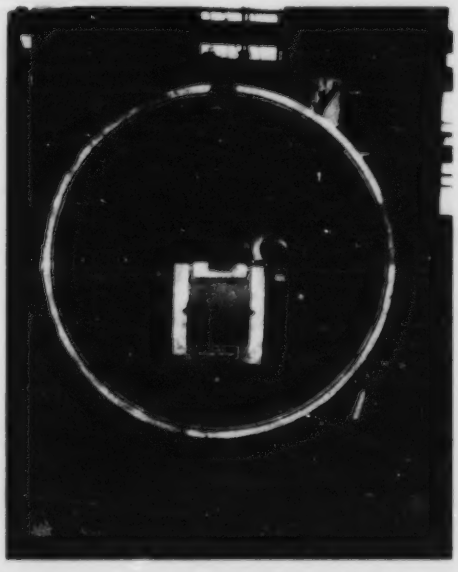
Equipment for desulphurizing steel melts by powder injection has been delivered and is being commissioned.

Data have been worked out for improved control of composition of air melts. The factors affecting nitrogen content have also been identified.

MOBILE FOUNDRY LABORATORY

An additional 24 foundries (see list below) were visited by the MFL during the past year, making a total of 76 foundries visited across Canada. In addition, an economic assessment of the visits was made by Kanata Consulting Group. Forty-one of the first 52 foundries visited were contacted in this evaluation. It revealed that $793 thousand in savings had already been realized and estimated that $5.2 million more would be generated over the next five years by technological improvements suggested during the visits. This is a saving of $3.9 thousand per employee for foundries employing fewer than 50 people and $1.7 thousand per employee for the larger foundries. The increased profits would generate an estimated $1.8 million additional taxes over the six year period. The MFL visits also resulted in the hiring of 15 professional or technical people and 8 unskilled workers by the 41 foundries.

Arrangements have been finalized to loan the MFL to the Association of Provincial Research Organizations to allow them to visit foundries in a



225 kg vacuum induction furnace used in the production of ultra-clean steels.

manner similar to EMR, Canada. Assistance has been given in training personnel from CRIQ and ORF for visits in Quebec and Ontario during 1986/87 fiscal year. If this exercise is successful, it could be expanded to other provincial organizations in subsequent years.

This method for technology transfer of taking the laboratory to the company nas demonstrated its merit and should be considered by other government departments with a mandate to assist Canadian industry.

MFL VISITS TO FOUNDRIES IN 1985/86

Associated Foundry Ltd.	Surrey, B.C.
Beaver Delta Machinery Ltd.	Guelph, Ont.
Benn Iron Foundry	Wallaceburg, Ont.
C.A.E. Machinery Ltd.	Vancouver, B.C.
C.S. Castings Ltd.	Orillia, Ont.
Cambridge Brass Foundry Ltd.	Cambridge, Ont.
Canron Inc. (Foundry Division)	St. Thomas, Ont.
Crane Canada Inc.	Brantford, Ont.
Findlay Foundry Ltd.	Carleton Place, Ont.
Fonderie Laroche Ltée.	Point Rouge, Que.
Fonderie Ouelette Inc.	St. Leonard d'Aston, Que.
Gamma Foundry Ltd.	Richmond Hill, Ont.
John T. Hepburn Ltd.	Toronto, Ont.
International Malleable Iron Co. Ltd.	Guelph, Ont.
ITT Aimco Industries Ltd.	St. Catherines, Ont.
ITT Grinell	Toronto, Ont.
Norwood Foundry Ltd.	Edmonton, Alta.
Rahn Metals & Plastics Ltd.	North Bay, Ont.
Redlaw Industries Inc.	Orillia, Ont.
Robar Industries Ltd.	Surrey, B.C.
Standard Brass & Aluminum Foundry Ltd.	Guelph, Ont.
Sovereign Castings Ltd.	Calgary, Alta.
Specialty Cast Metals Ltd.	Niagara Falls, Ont.
Titan Foundry Ltd.	Edmonton, Alta.

PAPERS PUBLISHED IN OUTSIDE JOURNALS AND CONFERENCE PROCEEDINGS

(authors from the Foundry Section underlined)

Bunr, R.K. and Sahoo, M..
"CANMET's Mobile Foundry Laboratory"; Canadian Copper Development Review; (22) May 1985.

Davis, K.G., Magny, J.C. and Ding Hui
"The inoculation of permanent mould cast iron"; Trans AFS; 93:939, 1985.

Ding Hui, Jing-xiang, Y. and Davis, K.C. "Thermal effects during the solidification of cast iron"; Trans AFS; 93:917, 1985.

Whiting, L.V., Sahoo, M. and White, D.W.G.
"Control of underside shrinkage in zinc-aluminum foundry alloys and the addition of trace elements"; Trans AFS; 93:475; 1985.

AVAILABLE PMRL REPORTS

PMRL 85-36(INT) Xu, J.C. and Palmer A.R. "Studies on the morphology and compositions of oxide inclusions formed in liquid steel after deoxidation with aluminum".

PMRL 85-45(INT) Szabo, E.I., Kular, A. and Gauthier, R. "Glyoxal bonded foundry moulds".

PMRL 85-52(INT) Szabo, E.I. and Gauthier, R. "Degradable foundry sand binders: Part 1".

PMRL 85-57(INT) Szabo, E.I. and Gauthier, R. "Degradable foundry sand binders: Part II".

PMRL 86-30(INT) Palmer, A.R. "The recovery of alloying elements in steel melts made in the PMRL induction furnaces".

PMRL 84-83(OP-J) Hui, Ding, Jing-Xiang, J. and Davis, K.G. "Thermal effects during the solidification of cast iron".

MRP/PMRL 84-86(OP-J) Sahoo, M., Whiting, L.V. and White, D.W.G. "Control of underside shrinkage in zinc-aluminum foundry alloys by the addition of trace elements".

MRP/PMRL 85-2(OP-J) Fegredo, D.M., Shehata, M.T., Palmer, A. and Kalousek, J. "The effect of inclusion type and control on the wear of an alloy rail steel".

MRP/PMRL 85-4(OP-J) Davis, K.G., Magny, J.G. and Hui, D. "The inoculation of permanent-mould cast iron".

PMRL 85-40(OP-J) Sahoo, M., Whiting, L.V., Chartrand, V.C. and Weatherall, G. "Effect of strontium on the structure and mechanical properties of zinc-aluminum foundry alloys".

PMRL 86-12(TR) Whiting, L.V. "Analysis of low-alloy steels in the Mobile Foundry Lab".

PMRL 86-13(TR) Whiting, L.V. "Analysis of cast iron in the Mobile Foundry Lab".

PMRL 86-14(TR) Whiting, L.V. "Analysis of tin bronzes and red brasses in the Mobile Foundry Lab".

PMRL 86-15(TR) Whiting, L.V. "Analysis of aluminum bronzes in the Mobile Foundry Lab".

PMRL 86-16(TR) Whiting, L.V. "Analysis of yellow brasses in the Mobile Foundry Lab".

PMRL 86-19(TR) Whiting, L.V. "Analysis of Alcan 432 and aluminum zinc alloys in the Mobile Foundry Lab".

PMRL 86-20(TR) Whiting, L.V. "Analysis of aluminum silicon alloys in the Mobile Foundry Lab".

PMRL 86-21(TR) Whiting, L.V. "Analysis of aluminum Alcan alloys 320-350 and aluminum magnesium in the Mobile Foundry Lab".

PMRL 86-24(TR) Whiting, L.V. "Analysis of Alcan 125, 135 and 143 alloys (AA355, 356 and 380) in the Mobile Foundry Lab".

One cost recovery report was completed by the foundry section in FY 85/86.

PRESENTATIONS

Buhr, R.K.
"The Mobile Foundry Laboratory"; Winnipeg, Man., Sept. 1985.

Buhr, R.K.
"Technology transfer and the MFL"; All Canadian Conf of AFS; Montreal, Que.; Oct. 1985.

Warda, R.D.
"Sensors and data acquisition"; COMPUCAST III - An AFS Conf; Des Plains, IL; Sept. 23-24, 1985.

Warda, R.D.
"CANMET's Mobile Foundry Laboratory - Its role in the Canadian foundry industry"; Fanshawe College Student Chapter of the AFS; London, Ont.; Oct. 15, 1985.

Warda, R.D.
"Evaluation of Ontario foundries through the eyes of the Mobile Foundry Laboratory"; Seminar of the Ontario Chapter of the AFS; Hamilton, Ont.; March 20-21, 1986.

GRANT AND MONITORING ACTIVITIES

DESIGNATED SCIENTIFIC AUTHORITIES AND LIAISON OFFICERS

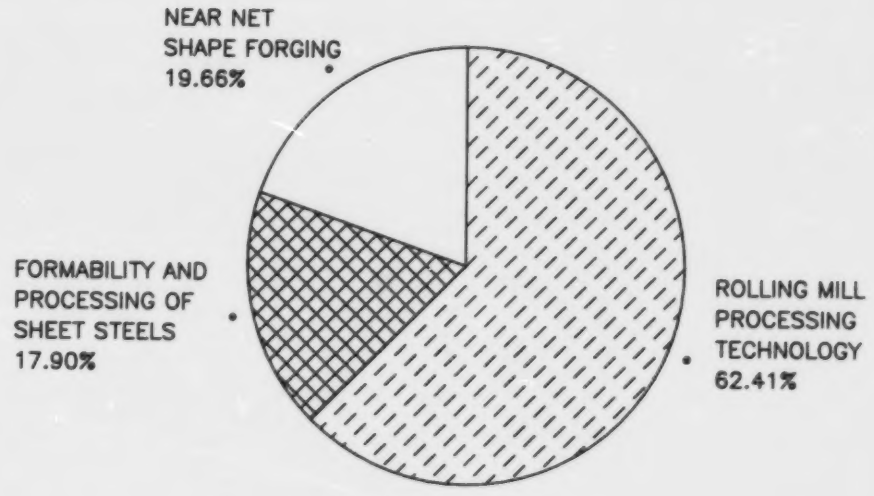
SA/LO	Performer	Project
R.K. Buhr	Robert Shnay and Associates	Professional Services
R.K. Buhr	Kanata Consulting Group	An evaluation of the Mobile Foundry Laboratory by its clients - Jan. 1986
K.C. Davis,	M. Salcudean, Univ. of B.C.	Mathematical modelling of flow in permanent moulds
K.C. Davis,	Falconbridge Ltd.	Influence of casting variables on the structure & properties of cast heat-resistant alloys
K.G. Davis,	Alloy Casting Industries Ltd.	To determine the dynamic toughness properties of cast steels

SA/LO	Performer	Project
A.R. Palmer,	Prof. R.L. Guthrie McGill University	Instrumentation for on-line liquid metal quality control in iron and steelmaking
A.R. Palmer,	Dr. G.A. Irons McMaster University	Optimization of injection technology for high quality steels Phase II

METAL FORMING SECTION

SECTION HEAD **A.F. CRAWLEY** **993-7136**

DEVELOPMENT OF METAL WORKING TECHNOLOGIES
(EXPRESSED AS PERCENTAGE DOLLAR EXPENDITURE)



(Excluding contract dollars)

Project	Lead Scientist	
ROLLING MILL PROCESSING TECHNOLOGY	A.F. CRAWLEY	993-7136
FORMABILITY AND PROCESSING OF SHEET STEELS	A.F. CRAWLEY	993-7136
NEAR NET SHAPE FORGING	A.F. CRAWLEY	993-7136

DEVELOPMENT OF METALWORKING TECHNOLOGIES

Facilities and processing techniques are being developed with the object of identifying, promoting and supporting advances in the technological capability of the Canadian primary and secondary metalworking industries. Meeting these objectives requires a fuller understanding of the fundamental mechanical metallurgy and mechanisms of material flow, their interrelationship, and the acquisition of sound base data.

Developments in metalworking technology must respond to a highly competitive international situation of intense competition based on ever increasing standards of quality consistency and economic costs. Research activities range from sophisticated metallurgy and innovative processes to complex highly mathematical modelling of deformation.

Current aspects of metalworking technology being investigated are:

- Rolling mill processing technology
- Formability and processing of sheet steels
- Near net shape forging

Within these projects, especially "Rolling Mill Processing Technology", work has been carried out as a contribution to research on marine and rail steels. Extensive cost recovery work has been carried out for large and small industry, government agencies and universities.

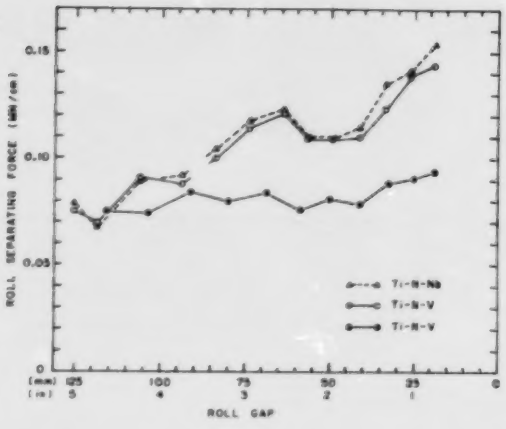
Realizing that future demands in material performance will lead to some displacement of metals by non-metals such as ceramics, metal matrix and fibre-reinforced composites and plastic, planning has begun to enter this field of advanced materials.

PMRL's work on the development of metalworking technology is recognized internationally. First, Sumitomo Metals, Japan has sent an engineer to PMRL to study for one year and carry out research. Second, an international symposium "Computer Modelling of Metal Fabrication Processes and Constitutive Behaviour of Metals" has been organized for May 1986.

ROLLING MILL PROCESSING TECHNOLOGY

The objective of this project is to develop rolling mill processes for modern high quality steel plate, strip and sheet based on the optimum utilization of Canadian industrial facilities and to demonstrate new technological opportunities by designing schedules incorporating thermomechanical processing and on-line accelerated cooling, by modelling and simulation of rolling, and by developing a fundamental understanding of the stress-strain profile developed in the deformation sequence.

Cam plastometer and rolling experiments to determine the effects of total strain, strain per pass and final pass temperature on austenite and ferrite grain refinement in Ti-N-V steels were continued. The results of the work defined requirements and the limitations of grain refinement attainable through the interaction of rolling temperature and drafting practice. The beneficial effects of molybdenum in further refinement of grain size under equivalent rolling conditions was also demonstrated. A significant outgrowth of this work was the application of the technology to processing of seamless steel tube. This research has involved a strong interaction between PMRL, industry and university.

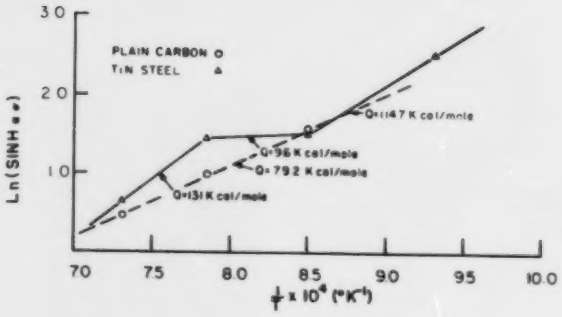


Development of rolling schedules for thick gauge plate steels: reduction in mill separating force by high temperature recrystallization rolling (closed symbols) compared with controlled rolling (open symbols).

The pilot scale on-line accelerated cooling system (OLAC) has been tested. Although these tests indicate that the system will function as designed, modifications have been undertaken to ensure consistency and reproducibility of operating conditions. These modifications are the addition of a filter system to remove particulates from the city water supply and a water cushion to prevent any water hammer which can damage the system as well as precluding control.

Turning to strip processing, base data was measured on the high temperature flow stresses of Nb, Ti, V and Ti-N steels at strain rates comparable with those experienced during strip rolling. These data were then applied to simulate and develop strip-rolling schedules. The potential of existing rolling theories to predict strip schedule and cam plastometer data for plain carbon and microalloyed steels was examined using the rolling theories of Hockett, Alexander and Sims. The results demonstrated that these theories are equally good provided non-homogeneity of deformation is taken into account.

Significant thrusts have been made in the mathematical modelling of rolling processes. These models are concerned not only with the rolling process but also with deformation mechanics and so have application to other processes. Modelling provides insight into the process, and a means of



Activation energies of deformation, Q, for a plain carbon and a Ti-N steel determined using cam plastometer generated flow stress values.

predicting power and load requirements and the development of microstructure. Project accomplishments are as follows: -

- A finite element code for the prediction of coupled thermal/mechanical behaviour has been written and is now undergoing verification.

- A simplified computer model based on the finite difference method and plastic flow theory has been completed. This model allows a prediction of coupled thermal/mechanical behaviour in rolling but requires much less computer time and capacity than the finite element code although with less precison.

- A drafting model has been developed to identify optimum rolling schedules that will result in improvements in quality and productivity in the production of plate. The initial model relates directly to pilot-scale rolling at CANMET. The model optimizes drafting schedules for best cost and product yield by using mathematical programming.

- Two approaches have been taken for optimization of microstructure and, therefore of mill capacity and properties. First, some existing models for grain size development have been incorporated into model-based energy input and roll force and torque prediction; second, existing models of microstructural development have been re-examined and computer programs written. The results indicated that modifications to these models were essential to take acount of grain growth between passes. This additional consideration resulted in increased predictive accuracy.

The effects of microalloy additions of niobium and/or boron on the hot-working characteristics of ultra-low carbon-bainitic steel compositions for linepipe grades have been studied under contract. Boron alone has been shown to produce only a small effect but in combination with niobium substantially retarded static and dynamic recrystallization and grain growth. The temperature and strain rate dependence of this retardation was also determined.

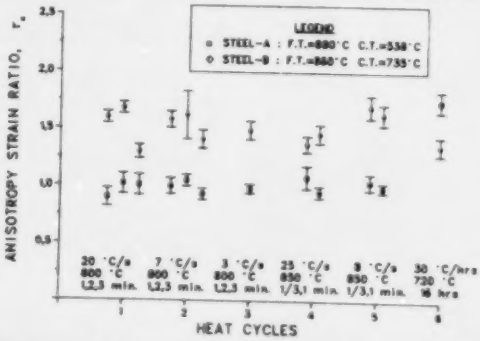
In a second contract, work has continued on the hot workability of strand-cast microalloyed steels. Preliminary work to design and machine high temperature tensile tooling and to develop computer programs for tensile-test control has enabled hot-tensile simulation of casting strain and rolling strain directly from the cast austenite state. In another part of this contract, rolling schedules have been developed for a range of strand-cast microalloyed compositions using hot-torsion simulation. A series of distinctly different rolling schedules were evaluated for each steel composition in terms of near flow stresses and the austenite and ferrite microstructures.

Formability and Processing of Sheet Steels

The objective of this project is to assist the Canadian steel industry to produce, and the metal forming industry to process, new high-quality steels (continuous-annealed plain-carbon high strength low alloy, dual-phase and galvanized) by advancing the understanding of the metallurgy and processing on ultimate formability.

The principal in-house work has focussed on the influence of the recrystallization of the base metal processed on a galvanizing line. The thrust of this research has been to define the roles of basic material characteristics such as grain size, precipitate morphology and crystallographic texture on the development of forming properties in an aluminum killed drawing quality (AKDQ) steel continuously annealed on a galvanizing line. Significantly it was known that low coiling temperature is detrimental to suitable texture development, that anisotropy and texture are improved by a high coiling temperature and improved still further by rapid heat-up rates and high annealing temperatures.

In associated work carried out under contract the forming behaviour of galvanized AKDQ steel has been studied. The results demonstrate that the galvanized layer does not have a large influence on formability compared to the base steel alone. Another significant result was the demonstration of the inferior adherence of an electrogalvanized



Influence of hot mill coiling temperature (C.T.) on the plastic anisotropy (r-value) of cold-rolled aluminum-killed drawing quality steel after simulated continuous (1-5) and batch (6) annealing cycles.

layer compared with a hot-dipped galvanized layer. Electrogalvanizing is a Japanese technology which is being introduced into North America.

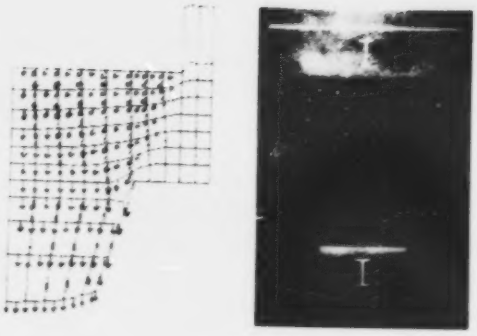
Near Net Shape Forging

The objective of this project is to develop forging techniques that reduce materials and energy usage by developing an understanding of the interplay of metal flow and microstructural development.

The principal effort has been the completion of a fully coupled thermal/mechanical finite element code which also has application to the the rolling process. The code is now undergoing validation.

A contract to upgrade the 500 ton press for advanced precision forging experiments has been completed. The new design and operational capability will permit temperature- and rate-controlled forging processes.

A second contract has been successfully completed to develop a technique using grey cast iron to measure local micro-strains so that fracture criteria can be related to local strain measurements.



Velocity fields calculated by finite element methods from wax experiments for 30% reduction by cold extrusion.

PAPERS PUBLISHED IN OUTSIDE JOURNALS AND CONFERENCE PROCEEDINGS

(authors from Metal Forming Section underlined)

Jonas, J.J., Akben, M.G. and Ruddle, G.E.
"Mechanical testing for the study of austenite recrystallization and carbonitride precipitation"; Proc Japan-Canada Seminar on Secondary Steelmaking; The Iron and Steel Institute of Japan, Tokyo, Japan, C-6, 1-12, 1985.

Ruddle, G.E., Baragar, D.L., and Crawley, A.F.
"Design of hot-rolling processes for thick-gauge HSLA plate"; 26th Mechanical Working and Steel Processing Conf; Oct. 17-19, 1984; Pittsburgh, PA Iron & Steel Soc of AIME; Warrendale, PA; 183-195, 1985.

Ruddle, G.E., Baragar, D.L., and Crawley, A.F.
"Process design and prediction for controlled rolling of thick-gauge HSLA plate"; Proc of Conf on HSLA Steels Technology and Application; ASM; Oct. 3-6, 1983; Metals Park, OH; 107-119; 1985.

AVAILABLE PMRL REPORTS

PMRL 85-43(INT) Smelsky, G. "Upgrading the PMRL 500 ton hydraulic press".

PMRL 85-20(OP-J) Ozsoy, I.C., Ruddle, G. and Crawley, A.F. "A drafting model for a hot plate rolling to minimize processing costs and crop losses".

PMRL 85-46(OP-J) Ruddle, G.E. and Baragar, D.L. "Grain refinement by recrystallization hot-rolling to achieve high-strength and notch-toughness in microalloyed steel plate".

PMRL 85-47(OP-J) Collins, L.E., Knight, R.F., Ruddle, G.E. and Boyd, J.B. "Laboratory development of accelerated cooling of microalloyed plate steels".

PMRL 85-19(J) Ozsoy, I.C. "Self-tuning control of drive motor speeds of a tandem mill".

MRP/PMRL 84-29(J) Ozsoy, I.C., Ruddle G.E. and Crawley, A.F. "Evaluation and assessment of roll-force and torque models for a hot-plate mill".

MRP/PMRL 84-44(J) Baragar, D.L. "The high temperature, high-strain rate behaviour of a plain carbon and an HSLA steel".

MRP/PMRL 84-73(J) Mainville, J., Crawley, A.F., Cousineau, E. and l'Esperance, G. "Influence of crystallographic texture during forming on dual-phase steels".

PMRL 85-34(TR) Too, J.J.M. and Xuejing Feng "A numerical method for the prediction of inhomogeneous deformation in rolling processes".

Four cost recovery reports were completed by the Metal Forming Section in FY 85/86.

PRESENTATIONS

(presenting author underlined)

Baragar D.L.
"The study of the high temperature, high strain rate behaviour of metals using a cam plastometer; 24th Annual Canadian Conf of Metallurgists; Vancouver, Aug. 18-21, 1985.

Collins, L.E., Knight, R.F., Ruddle, G.E. and Boyd, J.D.
"Laboratory development of accelerated cooling of microalloyed plate steels"; 1985 Conf on Accelerated Cooling of Steels, The Metallurgical Society of AIME; Pittsburgh, PA, Aug. 19-21, 1985.

Dogan, B., Boyd, J.D., Ozsoy, I.C. and Ruddle, G.E.
"The effects of microstructure on the through-thickness fracture properties of microalloyed steel plate"; 24th Annual Conf of Metallurgists, The Metallurgical Society of CIM; Vancouver, B.C., Aug. 18-21, 1985.

Jonas, J.J., Akben, M.G. and Ruddle, G.E.
"Carbonitride precipitation in HSLA steels"; 24th Annual Conf of Metallurgists, The Metallurgical Society of CIM; Vancouver, B.C., Aug. 18-21, 1985.

Jonas, J.J., Akben, M.G. and Ruddle, G.E.
"Mechanical testing for the study of austenite recrystallization and carbonitride precipitation"; the Japan-Canada Seminar on Secondary Steelmaking; The Iron and Steel Institute of Japan and the Canadian Steel Industry Research Association; Tokyo, Japan, Dec. 3-4, 1985.

Mainville, J., Crawley, A.F. and L'Esperance, G.
"Anisotropy in dual-phase steels"; 24th Conf of Metallurgists; Vancouver, B.C., August 20, 1985.

Maropoulos, T., Jonas, J.J. and Ruddle, G.E.
"Effect of boron on dynamic and static recrystallization in ultra low carbon Nb steels"; Intnl Conf on High Strength Low Alloy Steels (HSLA Steels '85), The Chinese Society of Metals; Beijing, China, Nov. 4-8, 1985.

Ozsoy, I.C., Ruddle, G.E. and Crawley, A.F. (Presented by Prof. A.T. Dinibutin)
"A drafting model for hot plate rolling to minimize processing costs and crop losses"; 7th (IASTED) Intnl Symp on Measurement and Control (MECO'85), The Intnl Association of Science and Technology for Development; Istanbul, Turkey, July 23-25, 1985.

Ruddle, G.E., Baragar, D.L.
"Grain refinement by recrystallization hot-rolling to achieve high strength and notch toughness in microalloyed steel plate"; 7th Intnl Conf on the Strength of Metals and Alloys (ICSMA 7); Montreal Que., Aug. 12-16, 1985.

Too, J.J.M. and Feng, Xuejing
"A numerical model for the prediction of inhomogeneous deformatation in rolling processes"; 35th Canadian Metal Physics Conf; Kingston, Ontario, June 5, 1985.

GRANT AND MONITORING ACTIVITIES

DESIGNATED SCIENTIFIC AUTHORITIES AND LIAISON OFFICERS

SA/LO	Performer	Project
D.L. Baragar	Enertec, Prof. J. Lenard University of New Brunswick	Mathematical modelling of the flat rolling process.
A.F. Crawley	McMaster University	Influence of friction on the prediction of formability and press shop performance of low-strength and high-strength steels

SA/LO	Performer	Project
G.E. Ruddle	Prof. M.G. Akben, McGill University	Effect of aluminum on recrystallization and precipitation in Mo and Nb steels
G.E. Ruddle	Prof. M.G. Akben, McGill University	Simulation of hot-working (controlled rolling) of continuous-cast HSLA steels
G.E. Ruddle	Prof. J.J. Jonas, McGill University	"Behaviour of microalloyed steels under industrial rolling conditions
G.E. Ruddle	Prof. J.J. Jonas McGill University	Effect of boron on precipitation and recrystallization kinetics in titanium and niobium bearing linepipe steels
J.J.M. Too	Queens University	Study of forgeability based on local strain and grain structure effects under varied deformation rate and temperatures
J.J.M. Too	Westinghouse Canada Inc.	Upgrading of a 500 ton forging press

RESEARCH CONTRACT REPORTS

701701 Crawley, A.F. "Technological assessment of Canadian Metal Forming Industry. Summary Report. Prepared by Robertson Nickerson Ltd.

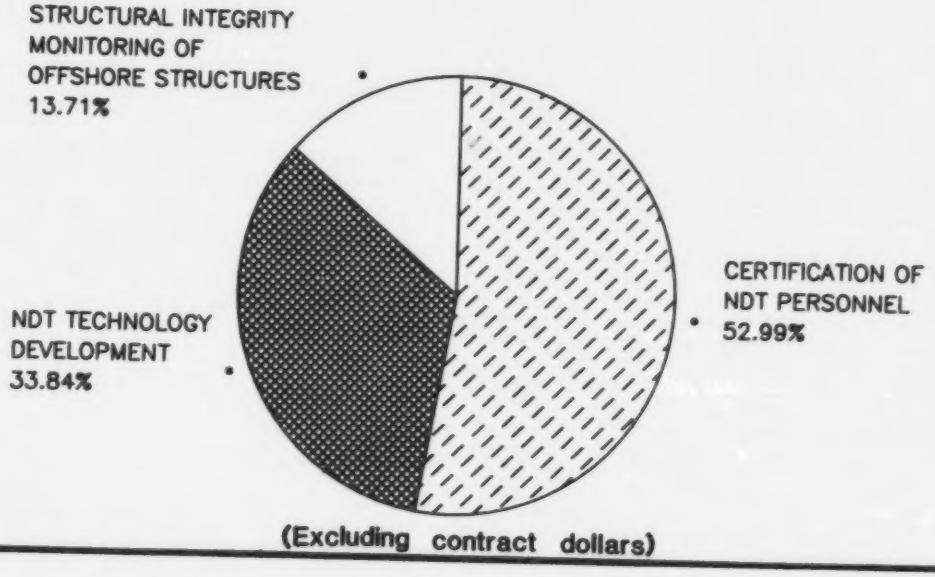
370232 Ruddle, G.E. "Prevention of duplex grain structures in controlled-rolled HSLA steel plate. Prepared by McGill University.

425101 Ruddle, G.E. "The effects of molybdenum, titanium and niobium on the hot working (controlled rolling) behaviour of linepipe steels. Prepared by McGill University.

NONDESTRUCTIVE TESTING SECTION

SECTION HEAD **V.L. CARON** **993-7105**

NONDESTRUCTIVE EVALUATION OF MATERIALS AND STRUCTURES
(EXPRESSED AS PERCENTAGE DOLLAR EXPENDITURE)

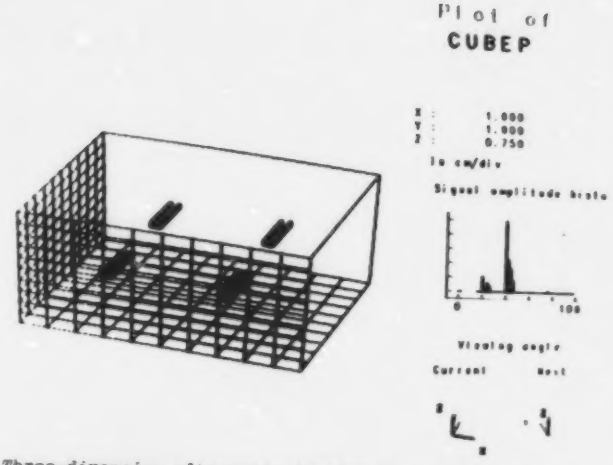

STRUCTURAL INTEGRITY MONITORING OF OFFSHORE STRUCTURES 13.71%
CERTIFICATION OF NDT PERSONNEL 52.99%
NDT TECHNOLOGY DEVELOPMENT 33.84%
(Excluding contract dollars)

Project	Lead Scientist	
CERTIFICATION OF NDT PERSONNEL	V.L. CARON	993-7105
NDT TECHNOLOGY DEVELOPMENT	V.L. CARON	993-7105
STRUCTURAL INTEGRITY MONITORING OF OFFSHORE STRUCTURES	V.L. CARON	993-7105

The activities of the nondestructive testing (NDT) Section encompass both the long-established procedures involved in the national certification of NDT personnel in Canada and the development of improved NDT technology. The R & D component focuses on both conventional and advanced technologies and reflects the greater level of sophistication that now characterizes NDT contributions to process and product quality control. All major projects take into account their potential commercial applications and eventually involve industrial participation. Other projects are targeted for energy transportation and recovery, especially in the offshore and Arctic.

Work continued in the area of ultrasonic inspection and characterization using optical and laser methods. This technology will enable samples to be inspected at elevated temperatures and will be amenable to the inspection of awkward shapes. A high-powered short-pulse laser is used to generate ultrasounds. The displacement of the ultrasound reflected from a flaw at the surface of the sample is then detected by a second laser and an optical interferometer. Ongoing work aims at making the technology sufficiently sensitive for laboratory and industrial applications. Two receiver systems are being developed. One is based on optical heterodyning (Michelson interferometer) and has a broad ultrasonic frequency response suitable for laboratory measurements. The other is based on the confocal Fabry-Perot interferometer which demodulates the Doppler shift produced by ultrasound. This system is immune to peturbations, such as vibrations, fumes and noises, depends less critically on optical alignment, and has good sensitivity on rough surfaces which makes it suitable for industrial inspection.

In the same area of defect detection and characterization by ultrasonics, a method has been developed to determine the length as well as orientation of a crack. This will be useful for monitoring crack growth. The tandem method which is quite often used to detect vertical defects in welds has been modified to give the precise location of the defect by measuring time of flight.



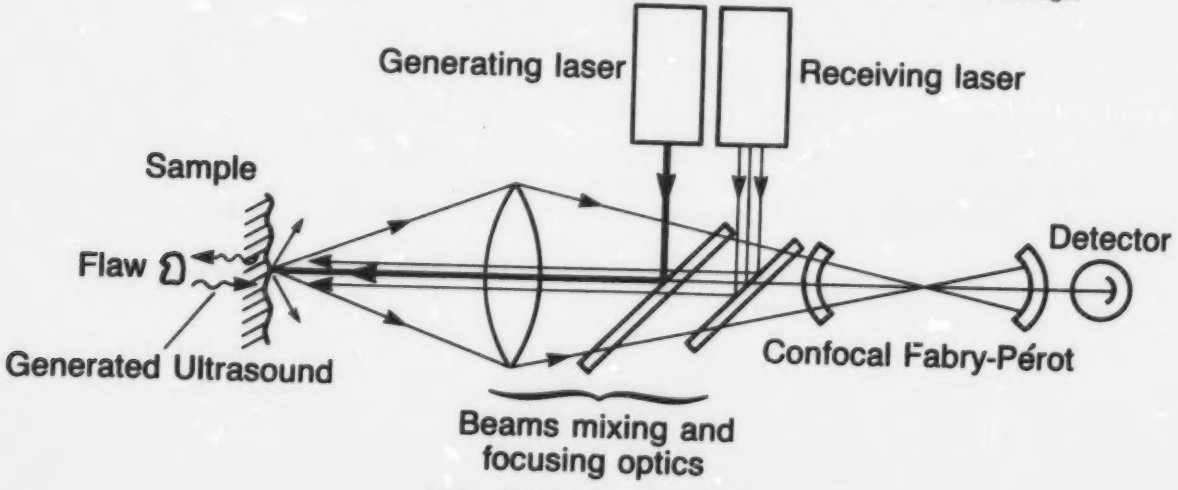
Three-dimension ultrasonic imaging of a rectangular block with four side-drilled holes.

In anotner project, development and experimental work continued on a scanning system using focussing probes and time-of-flight analysis to yield a three-dimensional image of defects located in heavy-section weldments.

A software development project was completed for application with the frequency-sweep eddy-current unit previously developed and which is now marketed worldwide.

Letters of interest were received from many countries with regard to an acoustic emission prototype which is to monitor defect formation during a welding operation. That unit was developed under contract and includes four transducers and complex software that can detect and locate potentially "noisy" defects such as weld cracking.

A contracted project aims at developing a magnetic system to measure bending stresses in pipelines particularly when they are laid over unstable terrain such as permafrost and river crossings.



Laser ultrasonics inspection system

CERTIFICATION OF NONDESTRUCTIVE TESTING PERSONNEL

The objective of this project is to certify nondestructive testing (NDT) personnel on a national basis. The strong growth of NDT reflects national concerns for (a) public safety through the need for structural integrity of engineering structures (nuclear plants, pipelines, etc.); (b) product quality and liability; (c) conservation of resources, and (d) productivity increase. The certification of qualified NDT personnel must be strictly controlled and be unaffected by adverse influences or pressures. In Canada, there is a general consensus of opinion that the certification of NDT personnel is a function best performed in the public sector.

Nondestructive testing personnel are now certified on a national level and the change from a two-level to a three-level system for certification was completed. More certification tasks were computerized.

On the international scene, PMRL assumes the secretariat responsibility of an ISO sub-committee in that area of certification. Progress was achieved towards drafting an international standard and international membership has increased.

NONDESTRUCTIVE TESTING TECHNOLOGY DEVELOPMENT

Recent years have witnessed growing research activity in raising the technological sophistication and application range of conventional NDT methods.

The acoustic emission monitoring prototype was further tested in welding tests completed on 3 in. thick steel plates, with defects being both deliberately introduced or avoided. Location of defects was accomplished and classification of acoustic signals generated during welding with pattern recognition algorithms yielded successful classification of available defects. Reciprocally, the tests gave no significant indications when sound welds were produced. The prototype will now be submitted to actual welding production tests under industrial conditions. Major savings in production costs and fewer problems could result from such real-time monitoring during welding by detecting, locating and even identifying defects and repairing them without waiting for welding completion.

In the area of laser-ultrasonics, the optical heterodyning ultrasonic receiver has been coupled in an evacuated enclosure located in a furnace for measurement and characterization of samples held at elevated temperatures. Work is in progress to characterize various aluminum/ceramic composites at elevated temperatures. The Fabry-Perot system has been modified into an all collinear set-up where all the free beams (generating, illuminating and the beam received from the surface) are superimposed, which arrangement is suitable for industrial inspection.

An eddy-current unit previously developed under contract uses a frequency sweep approach which makes it unique. Software development was concluded under PMRL contract to broaden its applications in defect detection and sizing.

Measurements of the effects of stress on the initial magnetization curve for pipeline steel samples have been performed. Magnetostriction measurements made on the same samples under various tensile and compressive phases were measured along anhysteretic and initial magnetization curves. This project was initiated for application to the nondestructive inspection of gas pipelines.

In ultrasonic technology, advances have been made in both transducer and defect characterization. A simple inexpensive electronic circuit has been designed and built to enhance the imaging of the beam profile of tranducers. In response to the demand of fracture mechanics the shape and size of defects need to be known. In collaboration with Tecnno-Scientific Co., a method to reconstruct a flaw in three-dimensional space has been developed. Experimental data has been collected on simulated flaws.

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"Infrared detection of ultrasonic absorption and application to the determination of absorption in steel"; Review of Progress in Quantitative Nondestructive Evaluation; ed. by D.O. Thompson and D.E. Chimenti, Plenum Press; 4B:965; 1985.

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"Infrared technique for measuring ultrasonic absorption in polycrystalline metals"; 8th Intnl Conf on Internal Friction and Ultrasonic Attenuation in Solids; June 3-6, 1985; Urbana, IL; Journal de Physique, ed. by A.V. Granato, G. Mozurkewich and C.A. Wert; 775; 1985.

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MRP/PMRL 84-88(TR) Monchalin, J-P. "Direct measurement of ultrasonic absorption".

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(Presenting author underlined)

Caron, V.
"A broad survey of several national documents on the certification of NDT personnel"; 11th World Conf on Nondestructive Testing (WCNDT '85); Nov. 3-8, 1985; Las Vegas, NV.

Chan, R., Lussier, B., Ferrara, A., Hay, R.D., Matthews, J. and Caron, V.
"A modularized data acquisition and processing system for intelligent NDT sensing"; 11th World Conf on Nondestructive Testing; Las Vegas, NV; Nov. 4, 1985.

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Mak, D.K.
"Beam entry point correction in crack tip measurement"; (poster presentation) Ultrasonic International; London, England; July 3, 1985.

Monchalin, J.-P.
"Optical detection of ultrasound at a distance by laser interferometry"; (poster presentation) 11th World Conf on Nondestructive Testing; Las Vegas, NV; Nov. 5, 1985.

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"Evaluation of ultrasonic inspection procedures by field mapping with an optical probe"; 24th Annual Conf of Metallurgists, Process Control in Materials Engineering, The Metallurgical Society of CIM; Vancouver, B.C.; August 19, 1985 and The American Society of Metals, Material Week; Toronto, Ontario; Oct. 15, 1985.

GRANT AND MONITORING ACTIVITIES

DESIGNATED SCIENTIFIC AUTHORITIES AND LIAISON OFFICERS

SA/LO	Performer	Project
V. Caron	Tektrend International Inc.	Development of on-line acoustic emission monitoring for welding thick-walled vessels
V. Caron	Manitoba Research Council	Identification of defects in cast steel components by vibration analysis
V. Caron	Tektrend International Inc.	Acoustic emission testing of compressed gas tube trailers
V. Caron	UK/HARWELL United Kingdom Atomic Energy Authority	Offshore inspection R & D service
D.K. Mak	Queens University	Fabrication of transducer for ultrasonic inspection of offshore structures
D.K. Mak	Techno Scientific	Automated ultrasonic test system for characterization of defects in weldments
D.K. Mak	NOVA, An Alberta Corporation	Selection of ultrasonic transducers for girth weld inspection
D.K. Mak	Techno Scientific	Market survey on automated ultrasonic imaging system
J.-P. Monchalin	Electromec Inc. (Tecrad Inc.) Québec, Qué.	Recherche sur les essais non-destructifs utilisant le principe des courants de Foucault

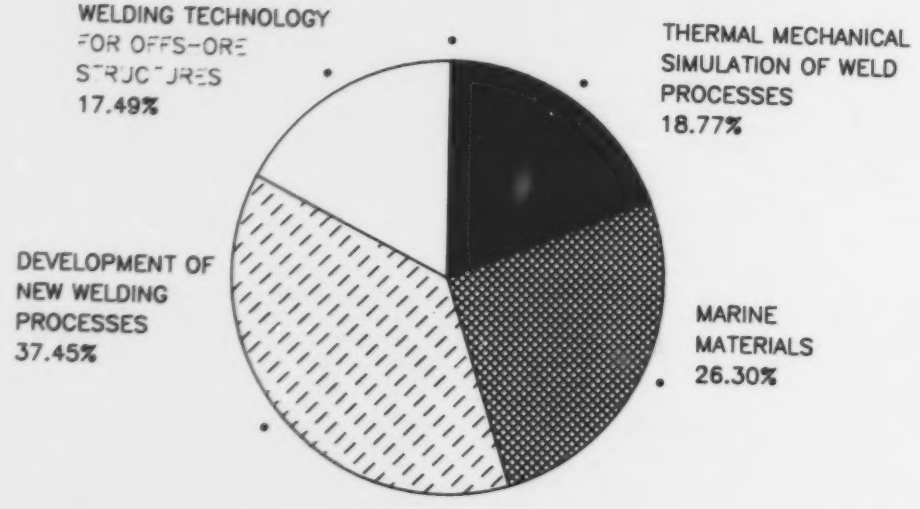
RESEARCH CONTRACT REPORTS

703802 Mak, D.K. "Automated ultrasonic testing system for the characterization of defects in weldments". Final report. Prepared by Techno Scientific Inc.

WELDING SECTION

SECTION HEAD **J.T. McGRATH** **993-7114**

WELD PROCESS DEVELOPMENT
(EXPRESSED AS PERCENTAGE DOLLAR EXPENDITURE)


WELDING TECHNOLOGY FOR OFFS-ORE STRUCTURES 17.49%
THERMAL MECHANICAL SIMULATION OF WELD PROCESSES 18.77%
DEVELOPMENT OF NEW WELDING PROCESSES 37.45%
MARINE MATERIALS 26.30%

(Excluding contract dollars)

Project	Lead Scientist	
THERMAL MECHANICAL SIMULATION OF WELD PROCESSES	J.T. BOWKER	993-7109
MARINE MATERIALS	R.D. MCDONALD	993-7114
DEVELOPMENT OF NEW WELDING PROCESSES	R. CHANDEL	993-7109
WELDING TECHNOLOGY FOR OFFSHORE STRUCTURES	J.E.M. BRAID	992-6395

The objectives of the research programs in the Welding Section are to assess new welding processes, develop welding procedures and evaluate the microstructure/mechanical property relationships in weldments for a wide range of applications such as Arctic ships, offshore structures, pressure vessels and pipelines. Highlights of work done both in-house and in contracted-out programs are summarized.

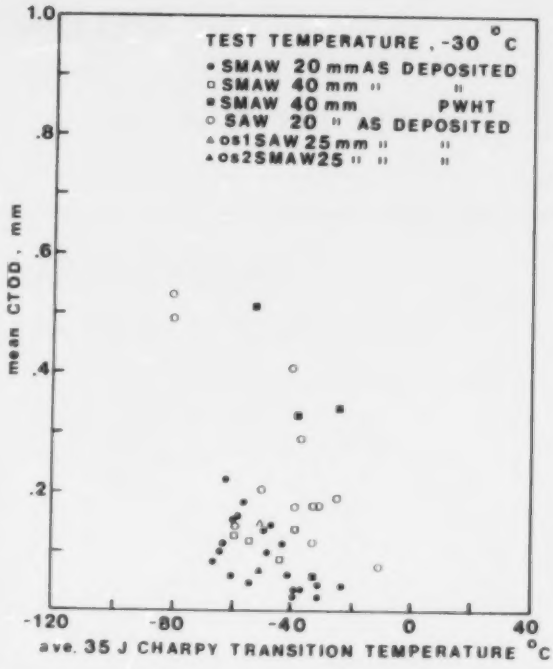
WELDING TECHNOLOGY FOR OFFSHORE STRUCTURES

In-house research work on the evaluation of fracture toughness and microstructure of currently available welding consumables for the shielded-metal arc (SMAW), flux-cored arc (FCAW) and submerged-arc (SAW) welding processes is 95% completed. The evaluation of 16 FCAW consumables was done under contract and has been completed; the experimental work for the evaluation of 20 SMAW consumables and 12 wire-flux combinations for SAW has also been completed. Full thickness (20 mm) crack-tip opening displacement (CTOD) tests were performed at -30°C and -10°C for each weld. A Charpy temperature transition curve was also determined for each weld. Several of the SMAW electrodes showed poor toughness performance in both the Charpy and CTOD tests and would not be suitable for use in welding offshore structures with a minimum design temperature of -30°C. The remaining SMAW electrodes had marginal performance. Similar conclusions could be made for the FCAW consumables evaluated. However, there are several SAW wire-flux combinations which give good Charpy and CTOD toughnesses for a -30°C design as a result of a better ability to control weld cleanliness and inclusion type and size distribution.

The effects of post-weld heat treatment (PWHT), used to relieve residual stresses, on the toughness of SMAW weld metals is being studied. Forty millimetre thick butt welds were prepared and the toughnesses in both as-welded and PWHT conditions were evaluated using CTOD and Charpy testing. There were no changes in Charpy toughness with PWHT for C-Mn weld metals while C-Mn-Ni weld metals showed a loss of toughness. Crack-tip opening displacement tests showed an improvement in toughness for both C-Mn and C-Mn-Ni welds with PWHT. The presence of Ni in the C-Mn-Ni welds is thought to increase the amount of martensite-austenite (MA) phase present in the as-welded structure compared with C-Mn weld metal and hence results in more and larger carbide precipitates in the PWHT condition. Investigations on the effects of Ni content, heat input and PWHT temperature on the amount of MA phase produced is underway. The varying effects of carbides on Charpy and CTOD toughness are also being investigated.

The results from the evaluation program have identified areas where consumables can be improved and work in this area is currently progressing under contract.

Other contract research related to welding of offshore structures includes a study of pulsed gas-metal-arc welding of thick-section steels for low temperature applications and a study of HAZ toughness of thick-section steels.



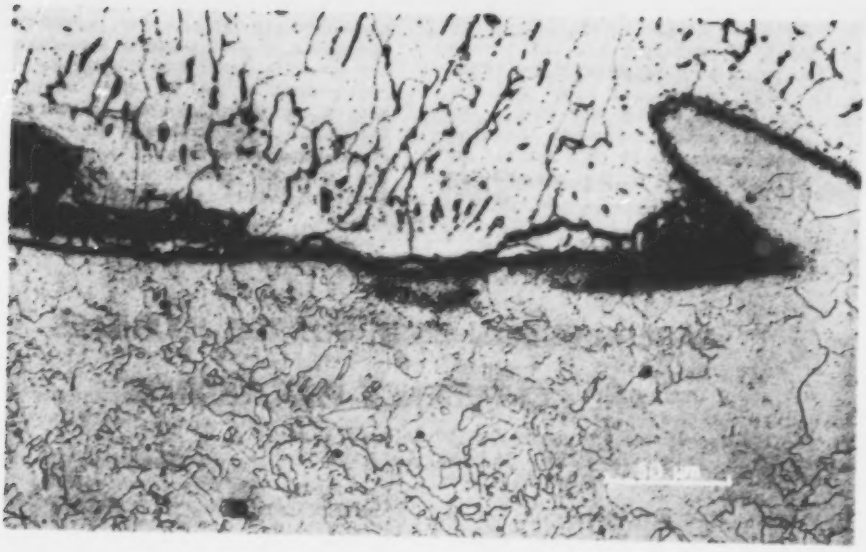
Interim data on mean crack tip opening displacement (CTOD) versus average 35 J Charpy transition temperature for a series of shielded-metal arc and submerged-arc weld metals tested at - 30°C for offshore and Arctic applications.

DEVELOPMENT OF NEW WELDING PROCESSES

Several in-house and contracted out programs are included in this project: studies of weld-overlay surfacing, narrow gap welding of pressure-vessel steels, development of a gas-metal-arc/submerged-arc combination processes, repair welding, laser welding and mathematical modelling of gas-metal-arc and submerged-arc welding processes.

In the area of weld-overlay surfacing, a cooperative program is underway with industry to assess the applicability of the electroslag strip-overlay process for the stainless steel lining of pressure vessels. A PMRL-initiated national program to determine the factors controlling weld overlay disbonding in reactor vessels includes participation by designers, fabricators, operators, welding consumable suppliers, research institutes and universities.

In narrow-gap welding, contract work continues on the in-shop application of the submerged-arc narrow-gap process for the fabrication of heavy-wall reactor vessels. A university-based program on gas-metal-arc narrow-gap welding has concentrated on the optimization of gas mixtures to provide high quality welds with the required notch toughness properties in Cr/Mo steels. The in-house narrow-gap work involved a study of various consumable combinations in the welding of SA 516 Grade 70 pressure-vessel steel by the submerged-arc narrow-gap process using a square-wave AC power source.

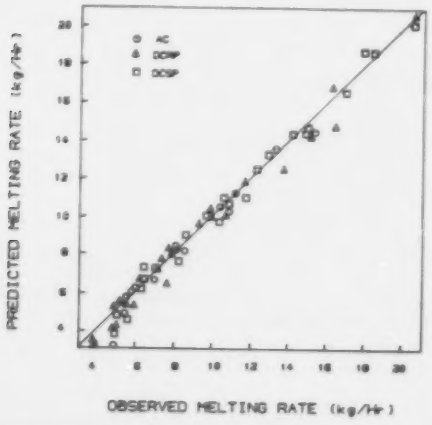


Hydrogen induced disbonding of an overlay weld.

The gas-metal-arc/submerged-arc combination welding process, developed under external contract, is now ready for shop trials after a successful bench-scale program which defined weld procedures and solved various problems associated with the process.

A study of repair welding of cast iron has continued under contract. Work is underway to study the effect of preheat temperature, buttering layer, etc., on the properties of repaired cast iron components used primarily in the mining industry.

A cooperative program has been initiated with NRC on laser welding. Finally, the in-house work on the development of mathematical models to correlate welding parameters with wire feed speed, melting rate, weld bead size and weld penetration is continuing.



Comparison of predicted and measured melting rates for the submerged-arc welding process.

THERMAL-MECHANICAL SIMULATION OF WELD PROCESSES

The objective of this project is to simulate metallurgical processes such as continuous casting and the microstructure and mechanical properties of the weld heat-affected zone. The Gleeble 1500 thermal/mechanical simulation is used to simulate the various heating, melting and cooling operations.

A major part of the study of weld heat-affected zone has been carried out by a PMRL research scientist on assignment in Japan at the National Research Institute of Metals. This work involves the evaluation of microstructure and mechanical properties of the HAZ in a range of Japanese steels suitable for offshore structure fabrication. Gleeble simulated and real weld HAZ prepared with energy inputs of 3 to 10 kJ/mm are being assessed. External contract work is being done on finite element analysis modelling of weld thermal cycles, grain growth and precipitate dissolution in the HAZ as well as the identification of precipitates in real weld and simulated HAZ for a range of offshore steels.

The program on simulation of continuous casting of a range of steels in cooperation with the Canadian steel industry is continuing with the identification of ductility troughs over a range of test temperatures.

MARINE MATERIALS

The objective is to develop welding procedures and evaluate mechanical properties in Arctic ship steel welds, and high strength steel weldments for submarine application.

The work on Arctic ship steel weldments has been concerned with the evaluation of mechanical properties and microstructures of weld metals and

heat-affected zones in high heat input submerged-arc weldments. The three steels investigated were LT60, EH36 and 350WT (strand-cast and CAB treated). For heat inputs up to 6 kJ/mm only the heat-affected zone in 350WT strand-cast steel met the notch toughness requirement of 40J at -40°C. The limited results on weld metal indicated that the notch toughness requirement could only be met up to heat inputs of 3 kJ/mm with the consumables tested.

The work on high-strength steel (HY80) weldments is being carried out in support of the Department of National Defence program on weldability of high-strength steels for submarine application. The tests on HY80 weldments prepared by submerged-arc welding indicated that the notch toughness requirement of 40J at -50°C could be met in weld metals prepared by two commercially available wire/flux combinations. The heat affected zone toughness measured at 1 mm from the fusion line was found to deteriorate at heat inputs $\geq$3 kJ/mm. Local brittle zones attributable to liquation cracking were responsible for the decreasing toughness in the heat-affected zone.

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ERP/PMRL 84-67(J) Braid, J.E.M. and McGrath, J.T. "The influence of microstructure and strain on the toughness of welded joints in structural steels for offshore applications".

ERP/PMRL 84-72(TR) Braid, J.E.M. "Draft CSA standard for repair welding of fixed steel offshore structures".

MRP/PMRL 84-77(INT) McDonald, R.D. and Gianetto, J.A. "Welding studies on HY80 steel using the submerged-arc process".

MRP/PMRL 84-78(INT) McDonald, R.D. and Gianetto, J.A. "Evaluation of welding techniques for Arctic ship plate (progress report - Dec. 1984)".

ERP/PMRL 85-16(OP-J) Chandel, R.S., Orr, R.F., Gianetto, J.A., McGrath, J.T., Patchett, B.M. and Bicknell, A.C. "The microstructure and mechanical properties of narrow-gap welds in 2.25 Cr - 1 Mo steel".

PMRL 85-35(OP-J) Shehata, M.T., Chandel, R., Braid, J.E.M. and McGrath, J.T. "Characterization of non-metallic inclusions in weld metals".

PMRL 85-41(OP-J) Chandel, R.S., Orr, R.F., Gianetto, J.A., McGrath, J.T. and Wright, B. "Some factors affecting the mechanical properties of submerged-arc narrow-gap welds".

PMRL 85-44(OP-J) Braid, J.E.M. and Gianetto, J.A. "The effects of PWHT on the toughness of shielded metal arc weld metals for use in Canadian offshore structure fabrication".

PMRL 85-23(TR) Bowker, J.T. "Simulation of continuous casting".

PMRL 85-59(TR) McGrath, J.T., Letts, M.W. and Gianetto, J.A. "The mechanical properties of submerged-arc metals in quenched and tempered pipeline fittings".

Two cost recovery reports were completed by the Welding Section during FY 85-85.

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(Presenting author underlined)

Bowker, J.T.
"Use of the Gleeble 1500 in the simulation of metallurgical processes"; Seminar at National Research Institute of Metal; Japan, Oct. 1985.

Bowker, J.T., Lau, T. and Lazor, R.B.
"Titanium steels for the Arctic: First report of HAZ study"; ASM Fall Meeting; Toronto, Ontario; October 1985.

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"Characterization of precipitates in weld HAZ"; Metal Physics Conf; Kingston, Ontario; June 1985.

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"Comparison of simulated HAZ microstructure and toughness for two high strength steels"; 18th Annual Tech Meeting of Intnl Metallographic Society; Denver, CO; July 1985.

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"Fracture toughness of SMA weld metal for offshore structures"; Welding Update '85; Toronto, Ontario; May 6, 1985.

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"Fracture toughness of welds for offshore structures"; Meeting of the Canadian Council of IIW; Oakville, Ontario; May 9, 1985.

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"The effects of PWHT on the toughness of shielded metal arc weld metals for use in Canadian offshore structure fabrication"; Welding for Challenging Environments; Toronto, Ontario; Oct. 1985.

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"Some factors affecting the mechanical properties of submerged arc narrow-gap welds"; Intnl Conf on Welding for Challenging Environments; Toronto, Ontario; October 1985.

Chandel, R.S. and Malik, L.M.
"Relationship between wire feed speed and submerged arc welding parameters"; Intnl Conf on Welding for Challenging Environments; Toronto, Ontario; Oct. 1985.

Chandel, R.S., Orr, R.F., Gianetto, J.A., McGrath, J.T., Patchett, B.M. and Bicknell, C.
"Relationship between microstructure and toughness of narrow gap welds in 2.25 Cr - 1 Mo steel"; Intnl Institute of Welding Annual Assembly; Strasbourg, France; Sept.1985.

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"Mechanical properties of welds in HY80 and A710 high strength steels"; Defence Research Establishment Atlantic Workshop "Fabrication and Inspection of Submarine Pressure Hulls"; Halifax, N.S.; May 1985.

McGrath, J.T.
"Current activities in IIW Commission X on brittle fracture"; Canadian Council of the Intnl Institute of Welding Workshop "Fracture and Fatigue of Welded Joints"; Toronto, Ontario; May 1985.

Shehata, M.T., Chandel, R.S., Braid, J.E.M. and McGrath, J.T.
"Characterization of non-metallic inclusions in weld metals"; Intnl Metallographic Soc Meeting; Denver, CO, July 1985.

GRANT AND MONITORING ACTIVITIES

DESIGNATED SCIENTIFIC AUTHORITIES AND LIAISON OFFICERS

SA/LO	Performer	Project
J.E.M. Braid	The Welding Institute (U.K.)	HAZ toughness of thick section steels
J.E.M. Braid	AMCA International	Evaluation of heat affected zone and weld toughness in selected steels - Phase I
J.E.M. Braid	AMCA International	Evaluation of heat affected zone and weld toughness in selected steels - Phase II

SA/LO	Performer	Project
J.E.M. Braid	AMCA International	Fabrication of shielded metal arc weldments
J.E.M. Braid	Welding Institute of Canada	CTOD testing of weldments
J.E.M. Braid	NOVA, An Alberta Corporation	Pulsed gas metal arc welding of thick section steels for low temperature applications
J.E.M. Braid	Canadian Liquid Air Ltd.	Inclusion effects on weld metals
J.E.M. Braid	AMCA International	Evaluation of flux-cored arc welding consumables for offshore and Arctic structure fabrication
R.S. Chandel	Babcock & Wilcox Canada	Development of stainless steel cladding technology
R.S. Chandel	AMCA International	Relationship between process parameters and wire feed speed for arc welding processes
R.S. Chandel	Carleton University	Prediction of weld thermal cycles, HAZ hardness, grain growth and precipitation
R.S. Chandel	Falconbridge Ltd.	Repair and reclamation technology of cast iron mining equipment
R.S. Chandel	AMCA International	"GMAW 2061"
R.S. Chandel	Welding Institute of Canada	"GMAW 2156"
J.T. McGrath	Stelco Inc.	Evaluation and development of the GMAW/SAW process
J.T. McGrath	Welding Institute of Canada	Evaluation of weld overlay disbonding
J.T. McGrath	Fluor Canada	C/Mn welding consumables for Arctic offshore and petrochemical application
J.T. McGrath	Univ. of Toronto	Characterization of precipitates in the weld HAZ for a range of offshore steels
J.T. McGrath	Welding Institute of Canada	Solidification cracking resistance of SAW weld metal
J.T. McGrath	Babcock & Wilcox Canada	Evaluation of factors controlling toughness of narrow gap welds
J.T. McGrath	Electrical and Optical Research	An analysis of hardness of laser welds
J.T. McGrath	Univ. of Alberta	Welding of heavy section pressure vessel steel by the narrow gap process

RESEARCH CONTRACT REPORTS

702710 Braid, J.E.M. "Fabrication of shielded metal arc weldments. Final report". Prepared by AMCA International.

702709 McGrath, J.T. "An analysis of hardness of laser welds. Final report". Prepared by Electrical and Optical Research.

702709 McGrath, J.T. "Narrow-gap welding of C-Mn and Cr-Mo steels". Prepared by A.C. Bicknell and B.M. Patchett.

702709 McGratn, J.T. "Evaluation and development of GMAW/SAW process for improving weld properties: Weld modelling considerations". Prepared by Welding Inst of Canada.

360022 McDonald, R.D. "Survey of the status of repair and reclamation technology in Canada Project RC99". Prepared by Welding Institute of Canada.

702710 Braid, J.E.M. "Evaluation of flux-cored arc welding consumables for offshore and Arctic structure fabrication". Prepared by AMCA Intnl.

702710 Braid, J.E.M. "CTOD testing of SMAW and SAW specimens". Prepared by Welding Institute of Canada.

TECHNOLOGY EXCHANGE

PARTIAL LIST OF COMPANIES, GOVERNMENT AGENCIES, UNIVERSITIES AND RESEARCH ORGANIZATIONS WITH WHICH PMRL HAS BEEN ASSOCIATED DURING FY 1985-86

Industry

A

A-1 Steel Foundry	Saskatoon, Sask.
Abex Corp.	Joliette, Que.
Abex Corp.	Mawa, N.J.
ACADZ Inc.	Montreal, Que.
ACG Technology Ltd.	Mississauga, Ont.
Adjeleian Allen Rubeli	Toronto, Ont.
AIMCO	St. Catharines, Ont.
Alberta Energy Co. Ltd.	Edmonton, Alta.
Alberta Rockwool Corp.	Calgary, Alta.
Alcan Canada Ltd.	Kingston, Ont.
Algoma Steel	Sault Ste. Marie, Ont.
Alloy Foundry	Merrickville, Ont.
Alpha Cast Inc.	Whitewater Wis.
AMAX	Michigan, Conn.
AMCA International	Montreal, Que.
AMCA International	Ottawa, Ont.
Ancast	Winnipeg, Man.
Arctec Canada Ltd.	Kanata, Ont.
Ardiem Inc. Corp.	Vancouver, B.C.
Asbestos Institute	Montreal, Que.
Associated Foundry	Surrey, B.C.
Astromet	Cincinnati, Ohio
Atlas, Steel	Welland, Ont.
Aurora Metals Division	Montgomery, Ill.
Avesta Stainless Inc.	

B

Babcock & Wilcox	Cambridge, Ont.
Badene, L. Associates	Willowdale, Ont.
Battelle	Columbus, Ohio
Bay Bronze	Winnipeg, Man.
Beaumart Ltée.	Contrecoeur, Que.
Beaver Dental Products	Morrisburg, Ont.
Belgen Foundry	Drummondville, Que.
Bell Northern Research	Ottawa, Ont.
Bethlehem Steel Corp.	Pittsburgh, Pa.
Bethlehem Steel Corp.	Bethlehem, Pa.
BHP Iron and Steel	Wollongong, Australia
Blaw - Knox	Chicago, Ill.
Blanchard Foundry	Saskatoon, Sask.
Brampton Foundries	Brampton, Ont.
Bow Valley Industries	Calgary, Alta.
Boart Canada	Toronto, Ont.
Brazloy Metals Inc.	Don Mills, Ont.
Bow Valley Offshore Limited Partnership	Halifax, N.S.
British American Bank Note Inc.	Ottawa, Ont.
British Steel Corp.	Middlesborough, U.K.
Brom Machine & Foundry Co., Ltd.	Winona, Minnesota
Brown Boggs Ltd.	Hamilton, Ont.
B and T MacFarlane Ltd.	Ottawa, Ont.
Burnstein Castings Ltd.	St. Catharines, Ont.

C

Cambridge Brass	Cambridge, Ont.
Canadian Bronze Co.	Winnipeg, Man.
Canadian General Electric	Peterborough, Ont.
Canadian Industries Ltd. (CIL)	Montreal, Que.
Canadian Insulation Service	Montreal, Que.
Canadian Liquid Air Ltd.	Montreal, Que.
Canadian Pacific Railways	Montreal, Que.
Canadian Stone Marine Ltd.	Iberville, Que.
Canadian Tungsten	Vancouver, B.C.
Canertech, Inc.	Winnipeg, Man.
Canron Foundry	Hamilton, Ont.

Canron, Inc.	Rexdale, Ont.
Canterra Energy	Calgary, Alta.
Caproco, Ltd.	Edmonton, Alta.
Carborundum Corp.	Bethlehem, Pa.
CBI Industries Inc.	Oak Brook, Ill.
Chadrien Ltd.	Ottawa, Ont.
Chevron Corporation	Richmond, Ca.
Chinook Fuel Innovations Ltd.	Calgary, Alta.
Chromasco Ltd.	Haley, Ont.
Climax Molybdenum Co	Golden, Colo.
C and M Engineering	Calgary, Alta.
Cominco	Sheridan Park, Ont.
Combustion Engineering - Superheater Ltd.	Ottawa, Ont.
Copper Development Assoc.	New York, N.Y.
Corrosion Control	Toronto, Ont.
Corrosion Service Co.	Toronto, Ont.
Crane Ltd.	Medicine Hat, Alta.
Creusot-Loire	France
Custom Aluminum	Cambridge, Ont.

D

Darling Bros. Ltd.	Montreal, Que.
Date Industries	Ayr, Ont.
Davie Shipbuilding	Lauzon, Que.
Davis Engineering	Ottawa, Ont.
Dayton Malleable Iron Co.	Dayton, Ohio
Dayton-Walther Foundry	Guelph, Ont.
de Havilland Aircraft	Toronto, Ont.
Delfab-Hallteck	Halifax, N.S.
Delta Group Consultants	Ottawa, Ont.
Det norske Veritas	Calgary, Ont.
Dofasco	Hamilton, Ont.
Dome Petroleum Ltd.	Calgary, Alta.
Dominion Bridge	Ottawa, Ont.
Dominion Bridge	Edmonton, Alta.
Dominion Engineering Works	Montreal, Que.
Domtar Chemicals	Toronto, Ont.
Dow Chemical	Midland, MI
Duffers Associates	Troy, N.Y.
Dynawest Projects Ltd.	Calgary, Alta.

E

Eastern Steel Castings	Hawesbury, Ont.
Eastview Engineering	Hull, Que.
Eaton-Yale	Chatham, Ont.
E.B. Eddy Forest Products Ltd.	Ottawa, Ont.
ECS Power Systems	Ottawa, Ont.
Eirich Canada	Maple, Ont.
Electromec	Quebec City, Que.
Elkem Inc.	Niagara Falls, N.Y.
Engineering Products of Canada Ltd.	Boucherville, Que.
Engineers India Ltd.	New Delhi, India
Enterprise Foundry	Sackville, N.B.
ESAB	Sweden
ESAB	Norway
ESAB	Montreal, Que.
Esco Corp.	Portland, Oregon
Esco Corp.	Port Coquitlam, B.C.
Esco Corp.	Port Hope, Ont.
Esso Resources	Calgary, Alta.
Exeltar Ltd.	Bedford, Que.
Exxon Production Research Company	Houston, Tx.

F

Fahramet Industries Ltd.	Orillia, Ont.
Falconbridge Nickel Mines Ltd.	Toronto, Ont.
Ferrco	Whitby, Ont.
Fleetwood Metal Ind.	Tilbury, Ont.
Fluor Canada	Calgary, Alta.
Fonderie Antique	Athabasca, Que.
Fonderie Poitras	L'Islettville, Que.
Fonderie Romuald	St. Romuald, Que.
Fonderie Saguenay	Chicoutimi, Que.
Fonderie Industriel Laforo	Quebec, Que.
Fondremy	Chambly, Que.
Foote Mineral Corp.	Chicago, Ill.
Ford Motor Co.	Deerborn, MI.
Forintek Canada Corp.	Ottawa, Ont.
Foster Wheeler	St. Catherines, Ont.

G

Galtaco	Guelph, Ont.
Gamma Foundries Ltd.	Richmond Hill, Ont.
Garrett Canada Ltd.	Hamilton, Ont.
General Casting Corp.	Milwaukee, Wis.
General Motors	Ste. Catharines, Ont.
Global Canatom	Cambridge, Ont.
Goodkey Weedmark & Associates	Ottawa, Ont.
GSW	Hamilton, Ont.
Gulf Canada, Ltd.	Calgary, Alta.
Gulf Canada Resources Co., Ltd.	Calgary, Alta.

H

Habitation Nordique	Quebec City, Que.
Haley Industries	Haley Junction, Ont.
Hall and Stavert Ltd.	Charlottetown, P.E.I.
Hamilton Foundry	Hamilton, Ont.
Hanson Material Engineering	Edmonton, Alta.
Hatch Associates	Toronto, Ont.
Hayes Stuart Inc.	Montreal, Que.
Heritage Foundry	Winkler, Man.
High Vacuum Systems Inc.	Brampton, Ont.
Highveld Steel and Vanadium Corp. Ltd.	London, England
Highland Foundry	Surrey, B.C.
Hirst Research Centre	London, England
Holmes Foundry	Sarnia, Ont.
Hooper & Angus Ltd.	Toronto, Ont.
Howmet Thermatech	Bouchervill, Que.
Husky Oil	Calgary, Alta.
Husky Oil	Lloydminster, B.C.

I

IMP Foundry Ltd.	Dartmouth, N.S.
Imperial Oil Ltd.	Toronto, Ont.
INCO	Toronto, Ont.
Industries USP	Lennoxville, Que.
Ingersoll-Rand Can. Ltd.	Cambridge, Ont.
Inproheat Ltd.	Vancouver, B.C.
International Harvester	Hamilton, Ont.
International Harvester	Chicago, Ill.
International Malleable Ltd.	
International Paint Co.	Montreal, Que.
Interprovincial Steel & Pipe Corp., Ltd.	Regina, Sask.
Intersteel Consultants Ltd.	Willowdale, Ont.
Itres Research Ltd.	Calgary, Alta.
ITT	Grinnell
ITT Aimco Ltd.	St. Catherines, Ont.
Ivaco	L'Original, Ont.

J

Jamaica Manufacturing Co., Ltd.	Prescott, Ont.
Jarrell-Ash	Waltham, Mass.
Jenkins Canada Inc.	Lachine, Que.
J.M. Asbestos Ltd.	Asbestos, Que.
Johnson-Matthey	Brantford, Ont.
Jones Fortier Advisors Ltd.	Pittsburg, PA

K

Kanmet Foundry	Cambridge, Ont.
Kashima Steel Works	Kashima, Japan
Kawasaki Steel Corp.	Chiba, Japan
Kelly Foundry and Machinery	Elkins, Va.
Kelsey Hayes Ltd.	Woodstock, Ont.
Kentucky Centre for Mining and Mineral Research	Lexington, Ky.
Kidd Creek Mines Ltd.	Edison, N.J.
Krupp-Quakertown	Cambridge, Ont.
Kulp Foundry	Stroudsburg, Pa.
Kwicki	Calgary, Alta.

L

La Fonderie Thetford	Thetford Mines, Que.
Lake Ontario Steel Corp.	Whitby, Ont.
Leaver, E.W.	Willowdale, Ont.
Lethbridge Iron Works	Lethbridge, Alta.
Levelton, B.H. and Associates	Vancouver, B.C.

Limpact Industries Ltd.	Cobourg, Ont.
Lincoln Electric	Toronto, Ont.
Little, A.D. and Associates	Cambridge, Mass.
Lloyd's Registry	London, U.K.
Lloyd's Registry	Montreal, Que.
Lobo and Associates	Paris, Ont.
Lumonics Inc.	Ottawa, Ont.
Lusjne Chain Co.	Sweden

M

Magaloy Foundry	Stratford, Ont.
Magdalen Silica	Montreal, Que.
Mainland Manufacturing	Vancouver, B.C.
Maritime Steel foundry	New Glasgow, N.S.
Mathews, Jas.	Milton, Ont.
Marex Welding Products Ltd.	Walthem Cross, U.K.
Masdon Corp.	Calgary, Alta.
Massey Ferguson	Brantford, Ont.
McLean Foundry	Brantford, Ont.
Metallurgical Consultants, Inc.	Houston, Tx.
Metals and Alloys Inc.	Toronto, Ont.
Minexpert Inc.	Montreal, Que.
Mitel Corp.	Kanata, Ont.
Mitsubishi	Canada
Mobil Oil	Halifax, N.S.
Modern Castings	Des Plaines, Ill.
Monarch Industries Ltd.	Winkler, Man.
Mondel Eng.	Mississauga, Ont.
Mueller Industries	St. Jérome, Que.

N

Niagara Bronze	Niagara Falls, Ont.
Nippon Steel	Kimitsu, Japan
Nomis Computer Systems Corp.	Ottawa, Ont.
Nonferrous Alloy Castings Ltd.	Mississauga, Ont.
Noranda Mines, Ltd.	Murdockville, Que.
Noranda Research Centre	Pointe Claire, Que.
Norsk Hydro	Oslo, Norway
Northern Telecom Canada Ltd.	Ottawa, Ont.
Nordco	St. John's, Nfld.
Norwood Foundry	Regina, Sask.
Nutech Precision Metals	Arnprior, Ont.
Nyes Foundry	Vancouver, B.C.

O

OCL Industrial Materials	Vancouver, B.C.
ODC/OILFAB	St. John's, Nfld.
Oilfab Haltech Ltd.	Dartmouth, N.S.
Olan Industries	Lake Stevens, Wa.
Omark Ltd.	Cambridge, Ont.
Optotek	Ottawa, Ont.
Orangeville Foundry	Orangeville, Ont.
Ortec Corp.	Oakridge, TEN.

P

Pacific Enercon	Grandforks, B.C.
Packer Engineering	Napierville, Ill.
Partec - Lavalin	Toronto, Ont.
Pergamon Press, Canada	Willowdale, Ont.
PetroCan	Montreal, Que.
Pfizer	Montreal, Que.
Pfizer International	New York, N.Y.
Philips Electronics	Canada
Plant Adjustment Bureau Ltd.	Moncton, N.B.
Port Weller Dry Dock Ltd.	St. Catharines, Ont.
Pratt and Whitney Canada Ltd.	Longueuil, Que.
Price Waterhouse Assoc.	Toronto, Ont.
Proto Manufacturing	Windsor, Ont.
Prudential Steel Ltd.	Edmonton, Alta.

Q

Quatar General Petroleum Corp.	Quatar
Quatic Chemicals	Cambridge, Ont.
Quebec Iron and Titanium	Sorel, Que.

R

Rahn Metals	North Bay, Ont.
Republic Steel Corp.	Buffalo, N.Y.

Reynolds Aluminum	Richmond, Va.
Ridge Foundry	San Leandro, Ca.
Robar Industry	Surrey, B.C.
Robertson, Jas. Foundry	Toronto, Ont.
Robertson-Nickerson	Ottawa, Ont.
Rockwell International	Troy, MI
Rolls Royce Canada Ltd.	Montreal, Que.
Roxul Corp.	Milton, Ont.
Russell & Co. Ltd.	Ottawa, Ont.

S

Servimet Inc.	Tracy, Que.
Shell Canada Resources	Calgary, Alta.
Sherritt-Gordon Mines Limited	Fort Sask., Alta.
Sherritt-Gordon Research Centre	Fort Sask., Alta.
Sidbec-Dosco	Contrecoeur, Que.
Sinteris Canada, Inc.	Blenheim, Ont.
SNC Inc.	Montreal, Que.
Sonco Steel Tubing	Brampton, Ont.
Spar Aerospace	Toronto, Ont.
St. John Foundry	St. John, N.B.
St. John Shipbuilding and Dry Dock Co.	St. John, N.B.
St. John's Marine	St. John's, Nfld.
St. Romvald Fonderie	Quebec City, Que.
Standard Induction Casting	Windsor, Ont.
Stainless Foundry & Engineering Corp.	Milwaukee, Wis.
Stanton Foundry	St. Hubert, Que.
Stanton Pipes Ltd.	Hamilton, Ont.
Steel Company of Canada (STELCO)	Burlington, Ont.
Steel Company of Canda	Hamilton, Ont.
Steel Engine Products Ltd.	Liverpool, N.S.
Steelflow Inc.	Okotoks, Alta.
Stepsan	Toronto, Ont.
Stittsville Foundry	Stittsville, Ont.
Sumitomo Steel Company	Houston, Tx.
SUNCOR	Sarnia, Ont.
Sydney Steel Corporation (SYSCO)	N. Sydney, N.S.
Syncrude Canada	Fort McMurray, Alta.

T

Tallman Bronze	Burlington, Ont.
Techno Scientific	Downsview, Ont.
Tektrend Int'l Ltd.	Lachute, Que.
Teledyne Cast Products	California
Terminal City Foundry	Vancouver, B.C.
Tonawanda Coke Corp.	Tonawanda, N.Y.
TransCanada Pipelines	Toronto, Ont.
Transportation Development Centre	Montreal, Que.
Trudeau, P.	Ottawa, Ont.
Turbine Components	Brantford, Conn.

U

Union Carbide	Montreal, Que.
Union Carbide	Toronto, Ont.
Union Gas	Chatham, Ont.
Union Screen Plate	Lennoxville, Que.
United States Steel Corp.	Monroeville, Pa.

V

Vada Industries Ltd.	Okotoks, Alta.
Versatile Vickers	Montreal, Que.
Viatek Ltd.	Calgary, Alta.
Vicinary Chain Co.	Spain
Vickers Canada	Montreal, Que.
Vickers Ruwolf Adams Foundry	Victoria, Aus.
Victoria Machining Depot	Victoria, B.C.

W

Wellington Foundry	Wellington, Ont.
Wells Foundry	London, Ont.
West Coast Transmission	Vancouver, B.C.
Western Foundry	Wingham, Ont.
Westinghouse Research and Development Centre	Pittsburgh, Pa..
Wilson Brass foundry	Scarborough, Ont.
Wolfedale Eng. Ltd.	Mississauga, Ont.
World University Service	Ottawa, Ont.
Wotherspoon Foundry	Oakville, Ont.

Y

York Barbell Co. Ltd.	Oakville, Ont.

Z

Zalev Bros.	Windsor, Ont.

Canadian Federal Government

A

Agriculture Canada	Ottawa, Ont.
Atomic Energy of Canada	Chalk River, Ont.
Atomic Energy Control Board	Ottawa, Ont.

C

Canada Customs	Ottawa, Ont.
Canadian Broadcasting Corp., Northern Services - Radio	Ottawa, Ont.
Canadian Coast Guard	Ottawa, Ont. St. John, N.B. Dartmouth, N.S.
Canadian International Development Agency	Ottawa, Ont.
Canadian National Marine	St. John's, Nfld.
Canadian National Railways	Montreal, Que.
Canadian Oil and Gas Lands Administration	Ottawa, Ont.
Canadian Pacific Railways	Montreal, Que.
Canadian Patents and Development Ltd.	Ottawa, Ont.
Canadian Transport Commission	Ottawa, Ont.
CANARCTIC Shipping Co.	Vancouver, B.C.
Consumer and Corporate Affairs	Ottawa, Ont.
Correctional Services	Ottawa, Ont.

D

Defense Research Est. Atlantic	Halifax, N.S.
Defense Research Est. Pacific	Esquimalt, B.C.

E

Eldorado Nuclear	Ottawa, Ont.
Export Development Corp.	Ottawa, Ont.
External Affairs	Ottawa, Ont.

I

Industry, Trade & Commerce	Ottawa, Ont.
International Development Research Centre	Ottawa, Ont.

L

Library of Parliament	Ottawa, Ont.

N

National Aeronautical Establishment	Ottawa, Ont.
National Defence, Dept. of	Ottawa, Ont.
National Defence, Dept. of	Halifax, N.S.
National Energy Board	Ottawa, Ont.
National Museums of Canada	Ottawa, Ont.
National Research Council	Ottawa, Ont.
National Research Council IMRI	Montreal, Que.
National Research Council-Tribology Laboratory	Vancouver, B.C.

P

Petro Canada	Calgary, Alta.
Public Archives	Ottawa, Ont.
Public Works Canada	Ottawa, Ont.

R

Revenue Canada - Customs and Excise	Ottawa, Ont.
Regional Economic Expansion Dept.	Halifax, N.S.
Royal Canadian Mint	Ottawa, Ont.
Royal Canadian Mounted Police	Ottawa, Ont.

S

Science & Technology - Ministry of State for	Ottawa, Ont.
Solicitor General of Canada - Inmate Affairs	Ottawa, Ont.
Standards Council of Canada	Ottawa, Ont.
Standards Council of Canada	Winnipeg, Man.
Supply & Services, Dept. of	Ottawa, Ont.

T

Tariff Board	Ottawa, Ont.
Trade and Commerce, Dept. of	Toronto, Ont.
Transport Canada	Ottawa, Ont.
Transport Canada - Aviation Safety Bureau	Ottawa, Ont.
Treasury Board of Canada	Ottawa, Ont.

U

US National Bureau of Standards	Washington, D.C.

W

Whiteshell Nuclear Research Est.	Pinawa, Man.

Universities and Other Organizations

A

Alberta, University of	Edmonton, Alta.
Algonquin College	Ottawa, Ont.
American Foundrymen's Society	Buffalo, N.Y.
American Foundrymen's Society	Des Plaines, Ill.
American Foundrymen's Society	Trois Rivières, Que.
American Hot Dip Galvanizing Assoc.	New York, N.Y.
American Iron and Steel Institute (AISI)	New York, N.Y. Bethlehem, Pa.
American Society for Metals	Metals Park, Ohio
American Society for Metals	St. Louis, Miss.
American Society for Testing Materials	Philadelphia, Pa.
American Welding Society	Miami, Fla.
Argonne National Laboratory	Chicago, Ill.
Asbestos Institute	Montreal, Que.

B

BC Hydro	Vancouver, B.C.
BC Research Council	Vancouver, B.C.
Bedford Institute	Halifax, N.S.
British Columbia, University of	Vancouver, B.C.
Bureau de recherches géologiques et minières	Paris, France

C

CAD/CAM	Cambridge, Ont.
Cambridge, University of	Cambridge, U.K.
Canadian Copper and Brass Development Assoc.	Toronto, Ont.
Canadian Electrical Association	Montreal, Que.
Canadian Institute of Guided Ground Transport	Kingston, Ont.
Canadian Institute for Metalworking	Hamilton, Ont.
Canadian Standards Association	Toronto, Ont.
Canadian Petroleum Association	Calgary, Alta.
Canadian Welding Bureau	Toronto, Ont.
Cape Breton Development Corp.	Cape Breton, N.S.
Carleton University	Ottawa, Ont.
CEGEP	Trois Rivères, Que.
Centre de Recherches Industrielles de Québec (CRIQ)	St. Foy, Que.
Central Electricity Generating Board	Gravesend, U.K.
Centre for Frontier Engineering Research	Edmonton, Alta.
Clarkson College	Potsdam, N.Y.
Concordia University	Montreal, Que.
CSIRA	Burlington, Ont.
CSMDT	Hamilton, Ont.

D

Dar Es Salaam, University of	Dar es Salaam, Tanzania
David Taylor Naval R & D Centre	Annapolis, Md.
Delft University of Technology	Delft, Netherlands

E

Ecole Polytechnique	Montreal, Que.
Ecole National Superieur des Arts et Metiers	Paris, France
Electric Power Research Institute	Palo Alta, Ca.
Energy, Dept. of	London, U.K.
European Coal and Steel Community (EEC)	Brussels, Belgium

G

Grey Iron Research Unit	Columbus, Ohio
Government of India Reactor Research Centre	Tamil Nadu, India

H

Hiroshima University	Hiroshima, Japan

I

INRS, Engerie	Varennes, Que.
Institt de Recherche de la Sidérurgie Française	St. Germaine en Laye, France
Institute for Atomic Energy	China
Institute for Research and Development	Haita, Israel
International Copper Research Assoc.	New York, N.Y.
IREQ	Varennes, Que.
International Lead-Zinc Research Organization	New York, N.Y.
Iron and Steel Institute of Japan	Japan

J

Japan Society for Tech. of Plasticity	Tokyo, Japan

K

Kawasaki Steel Corp.	Chiba, Japan

L

Laval University	Quebec City, Que.
Lehigh University	Bethlehem, Pa.
Lawrence Berkely Lab.	Berkeley, Ca.
London University - Imperial College	London, U.K.

M

Manchester University	Manchester, U.K.
Manitoba Research Council	Winnipeg, Man.
Massachussets Institute of Technology (MIT)	Cambridge, Mass.
McGill University	Montreal, Que.
McMaster University	Hamilton, Ont.
Memorial University	St. John's, Nfld.
Mohawk College	Hamilton, Ont.
Montreal University	Montreal, Que.

N

National Advisory Committee on Min. and Met. Res. (NACMMR)	Toronto, Ont.
National Association of Corrosion Engineers	Houston, Tx.
National Coal Board - Coal Research Estab.	U.K.
National Bureau of Standards Research Lab.	Washington, D.C.
New Brunswick, University of	Fredericton, N.B.
Northern College	Kirkland Lake, Alta.
Nova Scotia Power Corp.	Halifax, N.S.

O

Oakridge National Laboratory	Oakridge, Ca.
Ontario Hydro	Toronto, Ont.
Ontario Research Foundation	Mississauga, Ont.
Ottawa, University of	Ottawa, Ont.

P

Paris (University of)	Paris, France
Peking Institute of Metallurgy	Peking, China
Penn State University	State College, Pa.
Pulp and Paper Research Institute of Canada	Montreal, Que.

Q

Queen's University	Kingston, Ont.
Quebec Hydro	Quebec City, Que.
QIT-FER et Titane Inc.	Montreal, Que.
Queensland Water Commission	Australia

R

Research & Productivity Council of New Brunswick	Fredericton, N.B.
Royal Institute of Technology	Stockholm, Sweden
Royal Military College	Kingston, Ont.

S

Sandia National Laboratories	Albuquerque, New Mexico
Sandia National Laboratories	Livermore, CA
Saskatchewan Research Council	Saskatoon, Sask.
Singapore Institute of Standards and Industrial Research	Singapore
Stuttgart, University of	Stuttgart, W. Germany
Swedish Institute for Metals Research	Stockholm, Sweden

T

Technical Research Centre	Finland

Technical University of Nova Scotia	Halifax, N.S.
Toronto, University of	Toronto, Ont.
Trinity College	Dublin, Ireland

U

Univeridad Michoacama de San Nicolas de Hidalgo	Morelia, Mexico
Université de Sherbrooke	Sherbrooke, Que.
U.K. Atomic Energy Authority	London, U.K.
U.S. Bureau of Mines	Minneapolis, Minn. Oregon
U.S. Naval Research Lab.	Washinton, DC.
U.S. Steel Research Lab.	Munroeville, Pa.

V

Virginia State University	Virginia, USA

W

Waterloo, University of	Waterloo, Ont.
Western Ontario, University of	London, Ont.
Windsor, University of	Windsor, Ont.
Winnipeg, City Waterworks	Winnipeg, Man.
Welding Institute (The)	Abington, U.K.
Welding Institute of Canada	Oakville, Ont.
Wollongong, University of	Wollongong, Australia

STAFF ACTIVITIES

REPRESENTATION ON TECHNICAL COMMITTEES

INTERNATIONAL

1986 INTERNATIONAL CONFERENCE ON: EFFECTS AND CONTROL OF INCLUSIONS AND RESIDUALS IN STEELS:		
Organizing Committee	(chairman)	J.D. Boyd
INTERNATIONAL ASSOCIATION OF COMPUTATIONAL MECHANICS	(member)	J.J.M. Too
INTERNATIONAL CONFERENCE ON THE STRENGTH OF METALS AND ALLOYS (ICSMA-7)		
Organizing Committee	(member)	G.E. Ruddle
INTERNATIONAL CONFERENCE ON: SOLUTE DEFECT INTERATIONS: THEORY AND EXPERIMENT		
Organizing Committee	(member)	J.D. Boyd
INTERNATIONAL INSTITUTE OF WELDING		
Canadian Council	(chairman)	J.T. McGrath
Commission X, Residual Stress, Stress Relieving Brittle Fracture	(member)	J.T. McGrath
Commission XIII, Fatigue Testing Committee	(member)	O. Vosikovsky
11TH INTERNATIONAL CONGRESS ON X-RAY OPTICS AND MICROANALYSIS	Program Chairman	R.H. Packwood
11TH WORLD CONGRESS ON NDT		
International Panel on Certification of NDT Personnel	(member)	V.L. Caron
INTERNATIONAL JOURNAL OF PRESSURE VESSEL AND PIPING		
Editorial Board	(member)	J.T. McGrath
INTERNATIONAL ORGANIZATION FOR STANDARDIZATION		
Canadian Advisory Committee SC11, Steel Castings	(member)	V.L. Caron

TC17/SC16,	Steel for the Reinforcement and Prestressing ofConcrete	(member)	R.J. Brigham
TC25,	Cast Iron	(member)	R.K. Buhr
TC135/SC7	NDT Personal Certification		
	International Secretariat	(secy)	V.L. Caron
TC164,	Mechanical Testing of Metals	(member)	A.F. Crawley
		(member)	O. Vosikovsky

INTERNATIONAL SYMPOSIUM ON COMPUTER MODELLING OF FABRICATION PROCESSES AND CONSTITUTIVE BEHAVIOUR OF METALS

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SCRIPTA METALLURGICA

	(assoc. ed.)	W.R. Tyson

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Committee on Environment Improvement	(member)	R.K. Buhr
Committee on Electronic Data Processing	(member)	D.W.G. White
	(member)	J.J.M. Too
PMRL/CANMET Metallurgical Task Force on the CANMET Hydrocracker at Petrocan	(members)	R.S. Chandel V.L. Caron R.W. Revie

PMRL/Industry Steering Committee on weld overlay surfacing	(chairman)	J.T. McGrath
Program 6.5 Committee on Materials R&D for Offshore Structures	(chairman)	M. Sahoo
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PILP Joint Review Board for CANMET Portable X-ray Stress Diffractometer	(member)	D.W.G. White
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Chemical and Metallurgical Engineering Grant Selection Committee	(scientific) (secretary)	W.N. Roberts
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Metallurgical Society, Iron and Steel Section	(member)	R. Thomson
Metallurgical Society, Publications Committee	(chairman) (member)	J.D. Boyd A.F. Crawley
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CANADIAN SOCIETY FOR NONDESTRUCTIVE TESTING FOUNDATION		
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Properties of Materials	(members)	K.C. Wang/ W.R. Tyson
Reinforcing Material for Concrete	(member)	R.J. Brigham

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- Materials group	(member)	J.E.M. Braid
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- Working group on welding	(member)	J.E.M. Braid
- Corrosion protection sub-group	(members)	J.B. Gilmour R.J. Brigham
- Working Group 4 on materials	(chairman)	W.R. Tyson
- Working Group on fatigue	(member)	O. Vosikovsky
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Structural Steel	(member)	R.F. Knight
Joining Sub-Committee of Pipeline Steels Z183, Z184	(member)	J.T. McGrath
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	(chairman executive council)	R.W. Revie
INDUSTRIAL CONSULTING COMMITTEE FOR MONITORING THE RESEARCH ACTIVITIES ON ZINC-BASE FOUNDRY ALLOYS	(member)	M. Sahoo
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NORTHERN COLLEGE, KIRKLAND LAKE		
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UNIVERSITY OF WESTERN ONTARIO		
Surface Science Laboratory, Board of Directors	(member)	R.H. Packwood
WELDING INSTITUTE OF CANADA		
Research Board	(member)	R. Thomson

PMRL STAFF AND ORGANIZATION

LIST OF PROFESSIONAL STAFF

W.H. Erickson	B.Sc., M.Sc. (Mich. Tech.), Ph.D. (Durham), P.Eng.	Director

V. Krstic	B.Sc. (Belgrade), M.S. (Nis), Ph.D. (McMaster)	Visiting Fellow

METALS PROCESSING LABORATORY

R. Thomson	B.Sc., ARCST, Ph.D. (Glasgow)	Manager

FOUNDRY SECTION

R.K. Buhr	B.Eng. (McGill)	Section Head
K.G. Davis	B.Sc. (Birmingham), M.A.Sc. Ph.D. (U.BC.)	Res. Sci.
J.L. Dion	B.A.Sc. (Montreal) P.Eng.	Phys. Sci.
R.A. Matte	B.Eng. (Sherbrooke U.)	Eng.
G Morin	B.A.Sc. (Laval), P.Eng.	Eng.
A.R. Palmer	B.Sc., Ph.D. (London), P.Eng.	Res. Sci.
E.I. Szabo	M.Sc., Ph.D. (Nottingham)	Res. Sci.
R.D. Warda	B.A.Sc. (U.BC.), Ph.D. (Cambridge)	Res. Sci.
L.V. Whiting	B.Sc., M.Sc., Ph.D. (McGill) M.B.A. (Ottawa U.)	Res. Sci.

METAL FORMING SECTION

A.F. Crawley	B.Sc., Ph.D. (Glasgow) P.Eng.	Section Head
D.L. Baragar	B.Sc., M.Sc., Ph.D. (Queen's)	Res. Sci.
C. Galvani	B.Ing. (Montreal Univ.)	Phys. Sci.
G.E. Ruddle	B.A.Sc., M.Sc. (Waterloo) D.Sc. (Virginia) P.Eng.	Res. Sci.
J.J.M. Too	B.Sc. (Taiwan), M.Sc. (McGill), Ph.D. (Wales)	Res. Sci.

NONDESTRUCTIVE TESTING SECTION

V.L. Caron	B.A.Sc. (Laval), M.Eng. (Paris) P.Eng,	Section Head
G. Landry	B.A.Sc. (Montreal)	Phys. Sci.
D.K. Mak	B.Sc., M.Sc., Ph.D. (Toronto)	Res. Sci.
J.P. Monchalin	D.Eng. (Paris), M.Sc., Ph.D. (MIT)	Res. Sci.

WELDING SECTION

J.T. McGrath	B.A.Sc., M.A.Sc., Ph.D. (Toronto), P.Eng.	Section Head
J.T. Bowker*	B.Met., Ph.D., (Sheffield)	Res. Sci.
J.E.M. Braid	B.A.Sc. (Waterloo), Ph.D. (Cambridge)	Res. Sci.
R.S. Chandel	B.E. (Nagpur), Ph.D. (Birmingham), C.Eng. M.I.M.	Res. Sci.
R.D. McDonald	B.Sc. (Queen's), P.Eng.	Res. Sci.

METALS DEVELOPMENT LABORATORY

D.W.G. White	S.M., Sc.D. (M.I.T.), P.Eng.	Manager

CORROSION SCIENCE SECTION

R.W. Revie	B.Sc. (McGill), M.Eng. (R.P.I.), Ph.D. (M.I.T.)	Section Head
D.C. Briggs	B.Eng., M.Eng. (McGill), Ph.D. (Queen's)	Res. Sci.
R.J. Brigham	B.Sc., M.Sc., Ph.D. (McMaster)	Res. Sci.
J.B. Gilmour	B.Sc. (Queen's). Ph.D. (McMaster) P.Eng.	Res. Sci.
H.M. Hindam	B.Sc. (Cairo), Ph.D. (McMaster)	Res. Sci.
G.R. Hoey	B.Sc., M.Sc., Ph.D. (Toronto)	Res. Sci.
A.W. Lui	B.Sc., M.A.Sc. (Queen's), Ph.D. (Windsor)	Res. Sci.
V.S. Sastri	B.Sc., M.A., Ph.D. (State U of N.Y.)	Res. Sci.
V. Scepanovic	B.Eng. (Belgrade), M.Eng. Ph.D.(McMaster)	Res. Sci.

*On secondment to the National Research Institute of Metals, Japan.

ENGINEERING PHYSICS SECTION

W.R. Tyson	B.A.Sc. (Toronto), Ph.D. (Cambridge)	Section Head
R. Bouchard	B.Sc. (Laval)	Phys. Sci.
B. Faucher	Eng. INSA (Lyon), M.Sc. (Laval), Ph.D. (Ottawa), P.Eng.	Res. Sci.
J. Harbec	B.Eng. (McGill), P.Eng.	Phys. Sci.
G. Roy	M.Sc. (Silesian U.), Ph.D. (P.A.S.)	Res. Sci.
O. Vosikovsky	B.A.Sc., Ph.D. (Prague)	Res. Sci.
Hong Youshi	WUSC trainee from the Institute of Mechanics, Chinese Academy of Sciences, Beijing.	
K.C. Wang	B.A.Sc., Ph.D. (Rensselaer)	Res. Sci.

METAL PHYSICS SECTION

W.N. Roberts	M.A., Ph.D. (Leeds)	Section Head
G.J.C. Carpenter	B.Sc., Pn.D. (Wales)	Res. Sci.
E.J. Cousineau	B.Sc. (Carleton)	Phys. Sci.
R. Holt	B.A.Sc. (Toronto)	Res. Sci.
J. Ng-Yelim	B.A. (Carleton), B.Sc. (Ottawa U.)	Phys. Sci.
R.H. Packwood	B.Sc., Ph.D. (Birmingham)	Res. Sci.

METALLURGY SECTION

J.D. Boyd	B.A.Sc. (Toronto), Ph.D. (Cambridge)	Section Head
L.E. Collins	B.Sc., M.Sc. (Queen's), Ph.D. (M.I.T.)	Res. Sci.
A. Couture	B.A., B.A.Sc. (Laval), P.Eng.	Res. Sci.
B. Dogan	B.Sc., M.Sc., Ph.D. Univ. of Manchester, Institute of Science and Technology (UMIST)	Visiting Fellow
B.A. Euser	B.Sc. (Toronto)	Phys. Sci.
D.M. Fegredo	B.Sc., M.Sc., Dipl. I.I.Sc. Ph.D. (Sheffield), M.I.M.	Res. Sci.
R.F. Knight	B.Sc., M.Sc. (Queen's)	Res. Sci.
T.F. Malis	B.Sc., M.Sc., Ph.D. (Manitoba)	Res. Sci.
M. Sahoo*	B.Sc., B.E. (I.I.Sc., Bangalore) Ph.D. (U.BC.), P.Eng.	Res. Sci.
M.T. Shehata	B.Eng. (Cairo), Ph.D. (McMaster)	Res. Sci.
Z.S. Wronski	M.Sc. (Warsaw), D.Sc. (Warsaw Tech Univ.)	Res. Sci.
C.S. Champion	B.Sc. (St. And) PGCE (Cambridge)	Tech. Editor

*Seconded to Research Program Office.

STAFF CHANGES

The following people were appointed to PMRL during FY 85-86

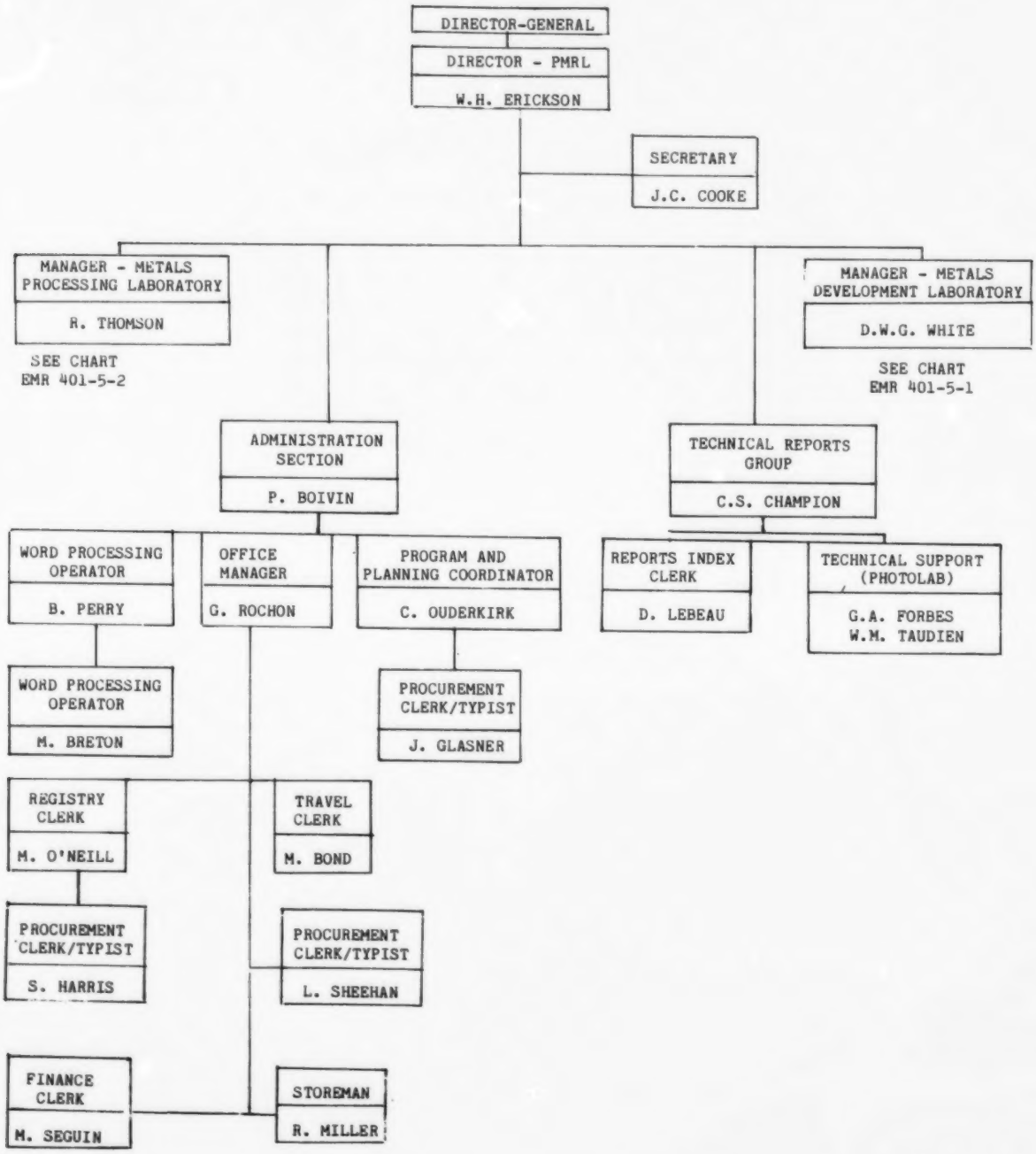
A. Bellefeuille	Term
P. Boivin	AS
R. Bouchard	PC
V. Krstic	Visiting Fellow
R. Malloy	EG-ESS
M.G. Seguin	CR
T.G. Starr	Term
G. Williams	EG-ESS
Z.S. Wronski	R.S.
H. Youshi	Visiting Fellow

The following people separated from PMRL during FY 85-86

A. Bellefeuille	End of Term
R.V. Carmody	Retired
M.J. Godden	Deceased
R. McDonald	Retired
C. Orzoy	Visiting Fellow
D.E. Parsons	Retired
R.R. Poirier	Resigned
R. Reardon	Retired
T.G. Starr	End of Term

PMRL ORGANIZATION CHARTS

(AS OF APRIL 1986)



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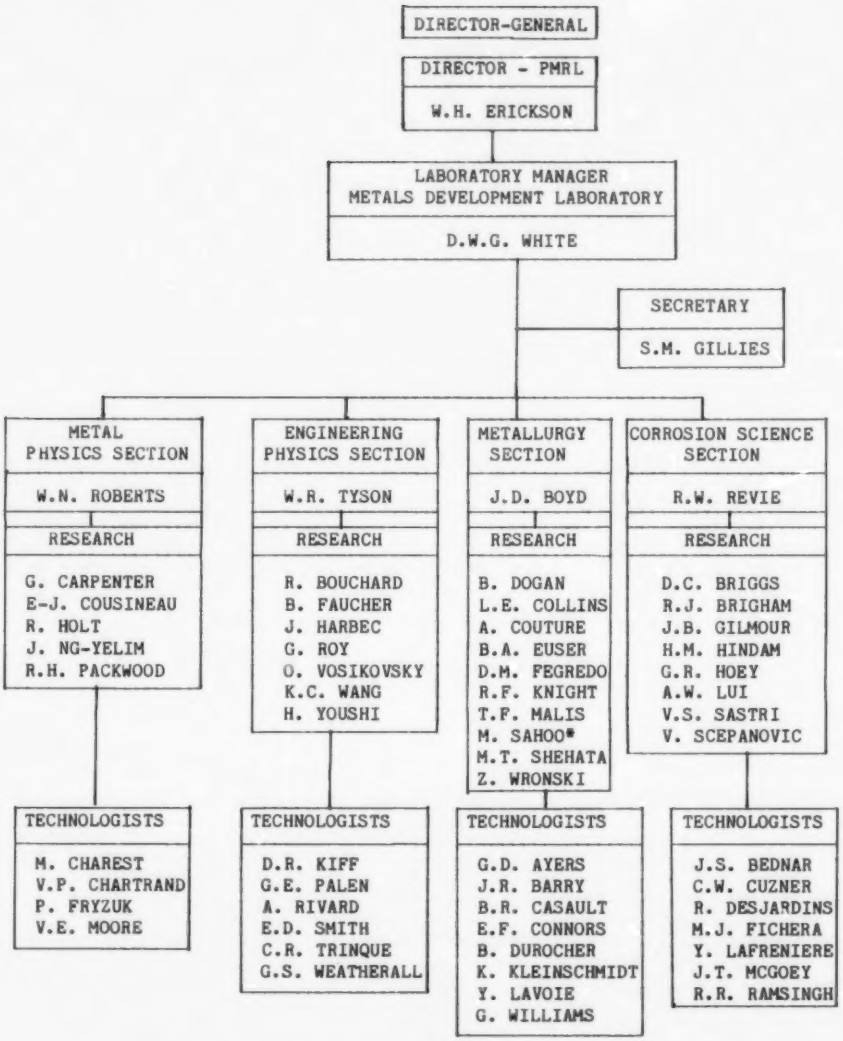
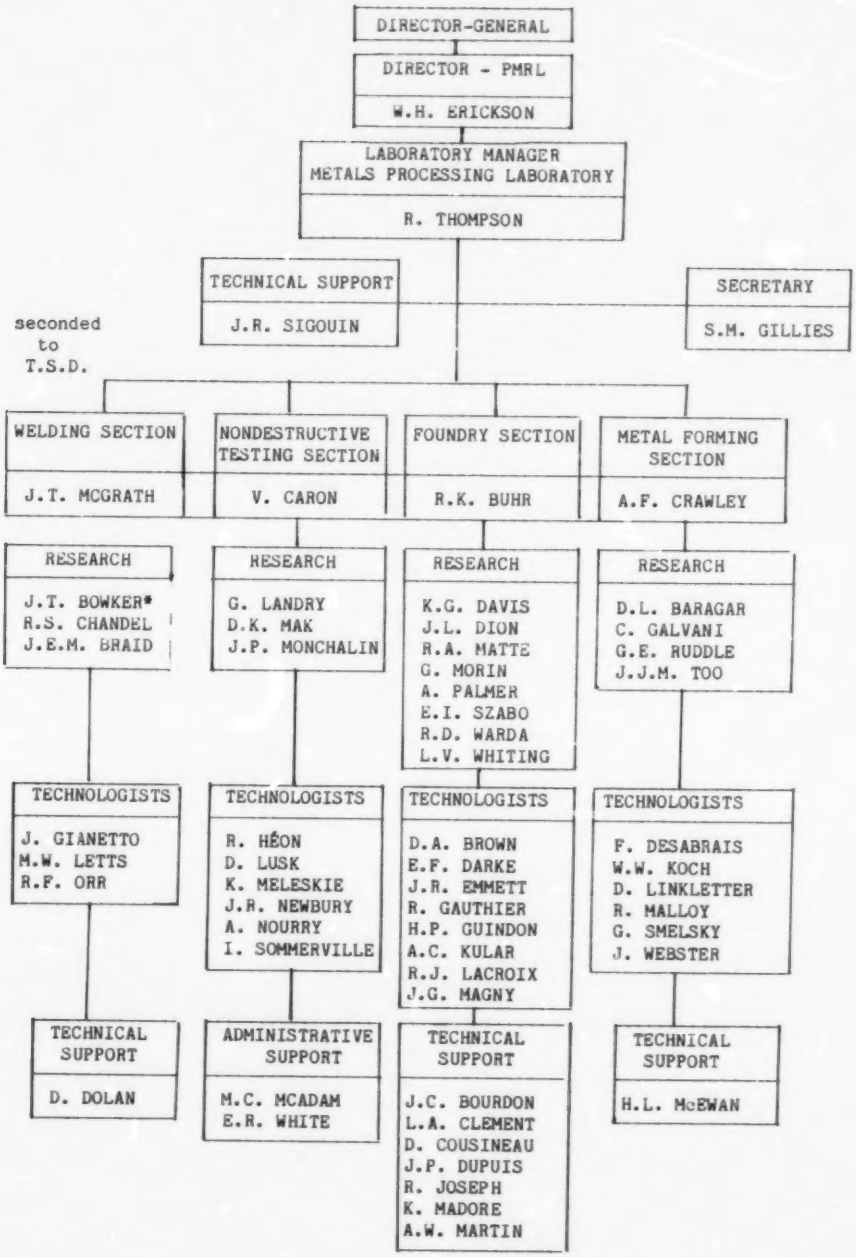


*Seconded to Program Office

CHART EMR 401-5-2



*Seconded to the National Research Institute of Metals, Japan

OBITUARY

M.J. GODDEN

Michael Godden, a research scientist with PMRL for 17 years, died suddenly on June 5, 1985, at the age of 41.

Born and educated in Ipswich, England, Mike went on to study metallurgy at the University of Sheffield where he was a first class honours student. His Ph.D. research on microstructural aspects of steels under Prof. A.G. Quarrell and Dr. J.C. Beech earned him the Brunton Medal for Metallurgical Research in 1967. He was to return to this early area of interest during his later years at PMRL.

With his bride of three days he arrived in Canada in 1967, to take up a position at PMRL in the Refractory Metals Section. His first task was to coax a new hollow-cathode-discharge furnace into operation and to characterize its operating parameters. This was a new concept for attempting to melt alloys of reactive and refractory metals on a commercial scale. This work completed, the emphasis of his research shifted to the physical metallurgy of titanium alloys, a topic that was to occupy him for most of his first eight years with PMRL. He soon established an expertise in this field by improving the ductility of alpha-titanium alloys and to characterizing precipitation and strengthening in certain beta-titanium alloys.

In 1976, a change in research priorities brought Mike back to research on the microstructure of steels. His electron-microscope studies contributed greatly to an understanding of the cause of low-toughness in weld heat-affected-zones. His work helped too to develop processes such as controlled rolling and accelerated cooling and to adjust the composition of steel to improve its toughness and weldability. By similar studies he helped to explain the disbonding of welded stainless-steel overlays in pressure vessels.

During his years at PMRL, Mike supervised various contracts with industry and universities and for the last four years was project leader for all of PMRL's line pipe steel activities. He also took on responsibility for upgrading and renovating the main metallographic facilities at PMRL, an activity that was nearing completion at the time of his death.

Aside from his work Mike was devoted to his family, he enjoyed cycling, swimming and skating, and was a keen and productive gardener. He was noted for his orchids and many descendants of his plants can be found in offices of PMRL.

Mike is survived by his wife, Beryl, and by their children Ian and Clare. His wry good humour and willing helpfulness are sorely missed by his colleagues who join together to express their sorrow at his loss.